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STEM DEFORMITY IN BLACK CHERRY

by Charles O. Rexrode

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Abstract

A 2-year study of stem deformity in black cherry on the Allegheny and Monongahela National Forests revealed that insects, disease, frost, and browsing by deer were the major sources of injury to the terminal shoots of seedlings and saplings. Twenty-seven species of insects from 19 families and 5 orders were associated with young black cherry trees. Of these species, *Archips* sp., and *Cecidomyia serotinae* O.S., caused the most stem deformity. The percentage of trees damaged by these two species of insects ranged from 0 to 43 *on six study areas* during 1976-77. Damage from black knot disease, *Apiosorina morbosa,* averaged about 3 percent. Frost injury was the primary cause of stem deformity in black cherry on the Monongahela National Forest during both years of the study.

INTRODUCTION

ON AN INDIVIDUAL-TREE BASIS, black cherry, *Prunus serotina* Ehrh., is second only to black walnut in timber value in the United States. In parts of Pennsylvania and West Virginia, black cherry is the most important species. However, in these two states there are large numbers of black cherry seedlings and saplings with a forked or crooked main stem. This results in pole stands with a high proportion of deformed trees, and a consequent reduction in timber value, so forest managers have emphasized higher quality through the selection and breeding of better stock. But many young plantations are low in quality because of poor growth and form, and many established plantations have saplings with a forked main stem. Also, seedlings have been planted on sites where the soil and vegetation are not conducive to vigorous growth.

Regardless of site condition, black cherry seedlings and saplings are damaged by frost, mammals, disease, and insects. Insects are suspected as a major source of damage to seedlings and saplings—even on the better sites. In this study I wanted to identify these insects and other major sources of injury which may result in deformity in black cherry.

METHODS

This study was conducted during the summers of 1976 and 1977 on the Allegheny National Forest in Pennsylvania, and on the Monongahela National Forest in West Virginia. Six areas of black cherry reproduction were selected; five were on the Allegheny and one was on the Monongahela. Study areas ranged in size from 2 to 20 acres, and 10 plots of approximately 20 trees each were established in each area. The trees ranged in height from 2 to 10 feet. Three of the study areas were part of a tree improvement study by the Eastern Region of the Forest Service, and were enclosed by a 10-foot-high fence.

Before cherry buds were completely open (early spring), some of the buds that exhibited insect entrance holes, failed to expand, or showed other damage were collected and dissected. The remaining damaged or abnormal buds, shoots, and stems were left intact for later evaluation. Some of the insects observed feeding on or within buds, shoots, and stems were collected and identified. A correlation was made between damage by specific insects and resulting tree injury.

Insects also were collected and identified monthly—from April through August in each area. During August of each year, the amount and type of damage from insects and other major sources of injury was determined for each study area.

RESULTS AND DISCUSSION

Insects, disease, frost, and browsing by deer were the major sources of injury to terminal shoots which resulted in stem deformity (Table 1). Twenty-seven species of insects from 19 families and 5 orders were associated with young black cherry trees (Table 2). However, of these species, a tortricid, *Archips* sp., and a gall midge, *Cecidomyia serotinae* O.S., caused the most stem deformity in black cherry.

The tortricid larvae enter developing shoots (Fig. 1) in late April and burrow upward for approximately 3 weeks; after this period, the larvae probably migrate to mature leaves on the same tree and resume feeding. The damaged terminal shoot takes on a wilted appearance in early May (Fig. 1). By the middle of the month, the shoot resembles one that has been damaged by frost (Figs. 2 and 3). The damaged shoot usually dies, and the function of the terminal is assumed by shoots that develop at a point lower than the apex of the original shoot, thus resulting in a deformed tree (Fig. 4). Tortricids accounted for 0 to 36 percent of the deformed stems on the study areas (Table 1).

Gall midge attack was evident on terminal shoots by mid-July. The terminal shoot or bud develops into an oval swelling about ½-inch in diameter; the swelling contains yellowish-orange maggots (Fig. 5). By late August, branches 1 to 2 inches long develop on and around many galls

Table 1.—Percentage of black cherry trees deformed on the Allegheny and Monongahela National Forests in 1976-77, by major source of damage.

Area	No. trees observed	Year	Tortricid	Gall midge	Black knot disease	Frost	Deer	Other	Total
Progeny test 1	400	1976	10	8	3	4	0	5[a]	31
	185	1977	36	7	2	0	0	2	48
Progeny test 2	200	1976	4	0	0	7	0	5	17
	200	1977	15	2	0	9	0	23[b]	50
Progeny test 3	330	1976	3	0	5	56	0	5	69
(Monongahela)	200	1977	4	0	4	62	0	5	76
Fertilized	200	1976	7	43	1	7	0	2	62
	200	1977	4	29	0	0	0	4	38
Natural stand	400	1976	0	1	1	10	3	2	19
	200	1977	29	0	1	2	7	0	40
Plantation	200	1976	0	5	0	0	90	0	95
(each tree fenced)	166	1977	0	2	0	0	83	0	85

[a]Lateral branch became dominant but main stem remained healthy.
[b]Mechanical damage due to plantation cleaning.

Table 2.—Insects collected from young black cherry trees in Pennsylvania and West Virginia, 1976-77.

Order	Family	Species
Coleoptera	Cantharidae	*Cantharis* sp.
	Cerambycidae	*Oncideres* sp.
	Chrysomelidae	*Orsodacne atra* (Ahrens)
		Paria quadriguttata LeC.
		Scelolyperus cyanellus (LeC.)
	Curculionidae	*Auletobius albovestitus* (Blatchley)
		Phyllobius oblongus (L.)
		Rhynchaenus canus (Horn)
	Elateridae	*Ampedus* sp.
		Ctenicera tarsalis (Melsh)
		Dalopius sp.
	Helodidae	*Cyphon ruficollis* Say
	Lagriidae	*Arthromacra aenea aenea* (Say)
	Melandryidae	*Symphora flavicollis* Haldeman
	Scarabaeidae	*Dichelonyx linearis* (Gyll.)
Diptera	Cecidomyiidae	*Cecidomyia serotinae* O. S.
Hemiptera-Heteroptera	Tingidae	*Corythucha* sp. Osborn and Droke
Hymenoptera	Cimbicidae	*Trichiosoma triangulum* Kirby
Lepidoptera	Coleophoridae	*Coleophora malivorella* Riley
	Geometridae	*Alsophila pometaria* (Harris)
		Calocalpe prunivorata Ferguson
		Phigalia titea (Cramer)
	Lasiocampidae	*Malacosoma americanum* (F.)
	Noctuidae	*Orthosia hibisci* (Guenee)
	Psychidae	*Fumaria casta* (Pallas)
	Tortricidae	*Archips* sp.
	Yponomeutidae	*Argyresthia* sp.

(Fig. 6). These branches continue to develop during the following year (Fig. 7), forming a tree with multiple terminal shoots (Fig. 8). The gall midge accounted for 0 to 43 percent of the deformity on the six study areas (Table 1).

Black knot disease, *A. morbosa,* was usually present but it accounted for little deformity (Table 1). Tumorlike cankers typical of this disease usually weaken and kill the affected terminal within a few years (Fig. 9).

Frost injury (Fig. 10) was the primary cause of stem deformity in black cherry on the Monongahela National Forest during both years of the study (Table 1). In some cases, 2 years of terminal growth was killed.

Browsing by deer is a serious threat to black cherry in areas on the Allegheny National Forest where the trees are not protected. In fact, in one area where each tree was enclosed by a 4-foot-high fence, 90 percent of the trees had terminal damage (Table 1). Terminal injury by deer is characterized by a breaking or tearing of the terminal during removal (Figs. 11 and 12).

The problem of stem deformity is a complex one where black cherry is grown in monoculture because of the variety of agents that injure the shoots. In some areas of Pennsylvania, browsing by deer is the most serious difficulty in regenerating black cherry. But even in the absence of deer, stem deformity caused by insects alone is serious.

Another complication is that, although damage may be found in less than 20 percent of the trees in a plantation on any year, the damage to shoots is compounded within the plantation over a period of years. In theory, when 20 percent of the trees are deformed each year, every tree in a plantation could be affected in five growing seasons. Also, the insects that cause the deformity have different habits and life cycles, thus making control difficult. However, once the feeding and development habits of these insects are known, stem deformity can be prevented by cultural or chemical control techniques.

Until more is known about the insects that cause deformity in black cherry, each plantation will have to be evaluated independently by the forest manager and the entomologist. Both must assess each insect infestation as to condition and long-range objectives of the plantation. For example, in the fertilized study area, the gall midge damaged 43 percent of the trees in 1976, and 29 percent in 1977 (Table 1). This amount of damage may be of less concern to a forester than an entomologist because the density of stocking is several thousand trees per acre, many more than are needed for a final crop. Also, the trees are growing at a rate of 3 to 4 feet a year, so they will not remain susceptible to injury for long.

In the meantime, if black cherry is grown in monoculture, good tree vigor should be maintained, thus favoring rapid shoot elongation. Also, sufficient stocking should be maintained so that deformed trees can be removed during early thinning.

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Figure 1.—*Archips* entrance hole on developing shoots (A), and wilting shoot (B).

Figure 2.—Late symptoms of *Archips* attack.

Figure 3.—*Archips* damage: brown and wilted terminal (A); larva (B); larval entrance (C); and exit holes (D).

Figure 4.—Deformed tree—injury caused by *Archips*.

Figure 5.—Stem gall caused by *C. serotinae.*

Figure 6.—Multiple branches developing on gall caused by *C. serotinae.*

Figure 7.—Multiple branches developing on gall 1 year later.

Figure 8.—Multiple branches several years after attack by *C. serotinae.*

Figure 9.—Black knot tumor.

Figure 10.—Frost damage—note flaccid appearance.

Figure 11.—Terminal injury by deer.

Figure 12.—Deer browse damage—note ragged and broken tips.

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RED MAPLE (*ACER RUBRUM* L.) GROWTH AND FOLIAR NUTRIENT RESPONSES TO SOIL FERTILITY LEVEL AND WATER REGIME

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Abstract

Red maple (*Acer rubrum* L.) seedlings were grown in a greenhouse using three treatments: two soil horizons, two soil moisture regimes, and three nutrient levels. Fertilization increased growth under moist conditions on the more fertile topsoil. Under dry conditions, fertilization had no effect on growth in subsoil, and slightly increased growth in topsoil. Without fertilization, growth was greater in the moist topsoil. Growth was most balanced when available soil N was 25 ppm, P was 25 to 75 ppm, and K was 75 to 100 ppm. Multiple regression equations relating growth to foliar nutrients were significantly different only for the subsoil.

INTRODUCTION

URBAN AREAS CREATE unique forest environments. Trees can be stressed by infertile soil, soil water deficit, pollution, and surfaces that act as heat traps. Vandalism and natural enemies also threaten new urban forests. Therefore, good survival and growth rates in the first few years are particularly important for the successful establishment of forests in urban areas. Appropriate fertilization may help seedlings to survive and improve their growth. Fertilization of urban forests is also thought to be potentially useful on sites recently developed on stripped soils or poor quality fill (Richards and Leonard 1973). However, optimum concentrations of soil nutrients for northeastern hardwoods are not well documented (Auchmoody and Filip 1973).

We studied the growth responses of red maple (*Acer rubrum* L.) seedlings to soil fertility levels and water regimes in a greenhouse. The general purpose of the study was to define the near optimum soil macronutrient level for urban forest trees that can be attained with complete fertilizers. Since complete fertilization was tested, nitrogen, phosphorus, and potassium levels were all adjusted in each treatment.

METHODS

Three fertility levels and two water regimes were used in a randomized block design on two soil horizons. Each treatment was replicated four times so that there were 48 experimental units.

The red maple plants were genetically identical 2-0 budded nursery stock of the cultivar 'October Glory.' They were closely matched in size with a height of about 62 cm and a diameter of about 1 cm at the root collar. Treatment pots of 11-liter capacity were filled with the prepared soil samples. After cold storage to break dormancy, the seedlings were planted one to a pot and allowed to establish for 6 weeks until the first flush of growth started on 4 March 1976. Soil moisture was maintained near field capacity during the establishment period, then controlled moisture treatments were begun and growth measurements were started.

The seedlings received 50 to 90 percent of full sunlight with a photoperiod of 11-1/2 to 15 hours. Temperatures varied from 19° to 24°C while relative humidity fluctuated from 45 to 80 percent.

Treatments

Soil horizons. Samples were taken from two soil layers: the subsoil, (silty clay loam, 30 to 84 cm depth) which had been exposed by the construction of a parking lot, and the topsoil, (silt loam, 0 to 30 cm depth) from an adjacent open area. Both soils were somewhat poorly drained variants of the Nixon series in Middlesex County, N.J. (U.S. Soil Conservation Service 1976). Soil fertility and physical properties immediately after collection are given in Table 1.

Table 1.—Physical and chemical properties of the two soil horizons

Soil property	Topsoil	Subsoil
Texture (%)		
Silt	50	59
Clay	16	35
Sand	35	6
pH	6.8	5.0
Organic matter[a] (% dry weight)	5.2	3.9
Bulk density (g/cc)	1.40	1.43
Total nitrogen (semimicro Kjeldahl, % dry weight)	0.173	0.072
Cation exchange capacity[b] (meg/100g)	15.93	15.60
Available nutrients[c] (ppm)		
Mg	432	307
P	64	11
K	106	50

[a] Loss on ignition.
[b] Extraction with NH_4OAC, pH = 7.
[c] Extraction with North Carolina reagent of 0.25N H_2SO_4 and 0.05N HCl with 4:1 ratio.

Macronutrient levels. Fertility levels (low and high) for each soil layer were established by adding nutrients in proportions based on an assumed soil mass of 2.24×10^6 kg/ha. The concentrations in the topsoil and subsoil controls were: N, 35 and 14 ppm; P, 64 and 11 ppm; and K, 106 and 50 ppm. Soils were amended to 25 ppm N, 75 ppm P, and 106 ppm K in the low fertility treatment and to 50 ppm N, 150 ppm P, and 212 ppm K in the high fertility treatment. Phosphorus was added in the form of monocalcium phosphate $Ca(H_2PO_4)_2$ (24.6 percent P); potassium as potassium sulphate K_2SO_4 (41.5 percent K). Both were thoroughly mixed with the soils before potting. Nitrogen was not added until the first flush of seedling growth. Equal amounts of nitrogen as ammonium nitrate NH_4NO_3 (35.5 percent N) were applied in solution at the beginning of the experiment then 4 and 8 weeks later, with each application representing 1/3 of the total applied N.

To increase the pH of the subsoil, 40 g of pulverized dolomitic limestone (minimum $CaCO_3$ 51.5 percent, minimum $MgCO_3$ 44.0 percent) was mixed thoroughly with the soil in each pot. This raised the subsoil pH to near 6.0.

Moisture regimes. To establish the watering schedule, soil samples were maintained at -0.3, -1, -3, and -15 bars as determined by a pressure membrane apparatus. The moisture tension curves and gravimetric soil moisture percentages were used to compare the two soils and determine the corresponding water potentials (Table 2).

The potted seedlings were subjected to two soil moisture treatments by simulated droughts of 2 and 7 days. At the end of each dry-down period, the pots (with soil, plants, and water) were weighed, moisture content was determined, and distilled water was added to return the soil to field capacity. This technique produced water potentials of approximately -1 bar for the moist treatment and -3 bars for the dry.

Measurement and analysis

The height of each plant was measured for 12 consecutive weeks after it was established. At the end of the 12 weeks, total height and diameter at 5 cm above the soil were measured. Dry weights of all plant parts (including roots $\geq$ 0.5 mm diameter) were determined after drying in a forced-draft oven at 80°C for 48 hours. All healthy, full-sized leaf blades of each plant (about 80 percent of all leaves) were dried separately and ground for chemical analyses. Nitrogen was determined by the semimicro-Kjeldahl method; phosphorus, magnesium, and potassium by the colorimetric method with an autoanalyser; and iron and manganese by atomic absorption techniques after digestion with a mixture of 80 percent nitric acid and 20 percent perchloric acid by volume.

Growth variables were not based on the nutrients that would be present in the soil if all the added nutrients were available. Rather, we reanalyzed the soil at the close of the experiment to determine the nutrients actually available. The reanalysis was done to correct for immobilization or fixation of the macronutrients so that recommendations for best seedling growth based on available nutrients, not fertilizer additions, could be made.

Table 2.—Soil moisture content (in percent dry weight) at different water potentials (in bars), with percentage of remaining available water

Item	Field capacity (-0.3 bar)	Wet treatment (-1.0 bar)	Dry treatment (-3.0 bar)	Wilting point (-15.0 bar)
		TOPSOIL		
Moisture content	22.5	21.2	14.3	8.4
Available water	100	91.0	42.0	.0
		SUBSOIL		
Moisture content	24.2	23.7	17.3	11.3
Available water	100	96.0	46.5	.0

RESULTS AND DISCUSSION

Optimum soil fertility depends on how growth is defined. In this study, we defined growth in terms of increased diameter and height, and the top-root dry biomass of the seedlings. We also examined foliar nutrient and soil nutrient levels for possible relationships that might suggest optimum conditions.

Disposition of added nutrients in the soil

Nutrients added to soils are not all available to the plant. Nitrogen may be leached, volatilized, or immobilized by microbes in the soil. Phosphorus becomes unavailable through chemical conversion to compounds only slightly soluble in the soil. Potassium may undergo fixation in the expanding lattice of some clay minerals.

The calculated available nutrients in the fertilized soils were compared with the measured available nutrients (Table 3). Since we added nitrogen in thirds, we assume it was available throughout the experiment at levels of 25 and 50 ppm in the low and high fertility treatments. The topsoil did not immobilize phosphorus at the low fertility level, and potassium was unaffected; however, some potassium was fixed at the highest fertility level under the driest condition. The subsoil, with a greater clay fraction, immobilized an average of about 75 percent of the added phosphorus and fixed about 45 percent of the added potassium.

Diameter growth

Diameter growth was significantly related to soil horizon and to water regime but not to fertility (Table 4). Diameter growth of seedlings was greatest in the topsoil maintained with the wet treatment. Reducing the water potential to −3 bars (dry treatment) reduced the diameter growth by about 12 percent. Our results and the results of other studies (Stransky and Wilson 1964, Loftus 1975) suggest that water availability is the major determining factor of diameter growth in young seedlings. And in our study, fertilization did not accelerate diameter growth.

Table 3.—Available nutrients and dry weight of tree biomass under three fertility levels and two water regimes after 12 weeks

Treatment	Nutrients			Biomass			Foliage
	N[a]	P	K	Top	Root	Total	
	-ppm-			*-gm-*			
			TOPSOIL				
Wet							
Control	20	73	102	20.0	15.1	35.1	8.3
Low	20	76	101	22.0	16.2	38.1	8.9
High	21	118	205	16.2	10.9	27.1	5.5
Dry							
Control	22	71	109	12.4	10.8	23.2	3.3
Low	21	75	108	11.1	12.6	23.7	3.0
High	22	106	161	10.5	10.6	21.1	2.5
			SUBSOIL				
Wet							
Control	10	14	52	18.0	16.8	34.8	5.1
Low	10	28	75	20.6	16.3	36.9	6.7
High	13	48	162	23.7	11.2	34.9	10.2
Dry							
Control	9	13	51	11.3	11.5	22.8	2.5
Low	10	27	77	13.8	12.3	26.1	3.5
High	12	42	148	11.8	10.1	21.9	3.3

[a]Assumed available at 25 and 50 ppm in the low and high fertility levels.

Table 4.—Summary of analyses of variance of plant growth variables

Variable	Factor						
	Soil horizon (S)	Water regime (W)	Fertility level (F)	SxW	SxF	WxF	SxWx
Stem diam (mm)[a]	*	**					
Height (cm)		**			**		
Ht increment (cm)		**			*		**
Dry weights (gm)							
Total		**					
Top		**					
Root		**	**				
Foliage		**			**		**
Stem		**					
Top/root ratio		**	*		*	*	
Foliar nutrients							
Nitrogen(%)		**	**				
Phosphorus(%)	**						
Potassium(%)	*		*	*			
Calcium(%)							
Magnesium(%)	**		**				
Manganese(ppm)	**	**		*			
Iron(ppm)	**	*				*	

* = $p<0.05$,
** = $p<0.01$.
[a]Measured at 5 cm above soil.

Table 5.—Foliar nutrient levels for all treatments[a]

Treatment	N	P	K	Ca	Mg	Mn	Fe
	-percent-					*-ppm-*	
Wet				TOPSOIL			
Control	2.23	0.223	0.84	1.16	0.41	413	199
Low	2.59	.215	.76	1.19	.41	384	212
High	2.88	.193	.89	1.20	.43	373	198
Dry							
Control	2.71	.210	.72	1.23	.43	546	189
Low	3.19	.205	.63	1.21	.48	577	230
High	2.96	.175	.86	1.24	.45	570	231
Wet				SUBSOIL			
Control	2.08	.138	.66	1.06	.47	568	302
Low	3.09	.168	.60	1.22	.52	540	231
High	2.51	.135	.77	1.10	.49	450	201
Dry							
Control	2.59	.148	.80	1.15	.44	577	279
Low	3.10	.148	.66	1.20	.52	581	278
High	3.22	.170	.73	1.33	.51	575	306

[a] Each value is the mean of four seedlings.

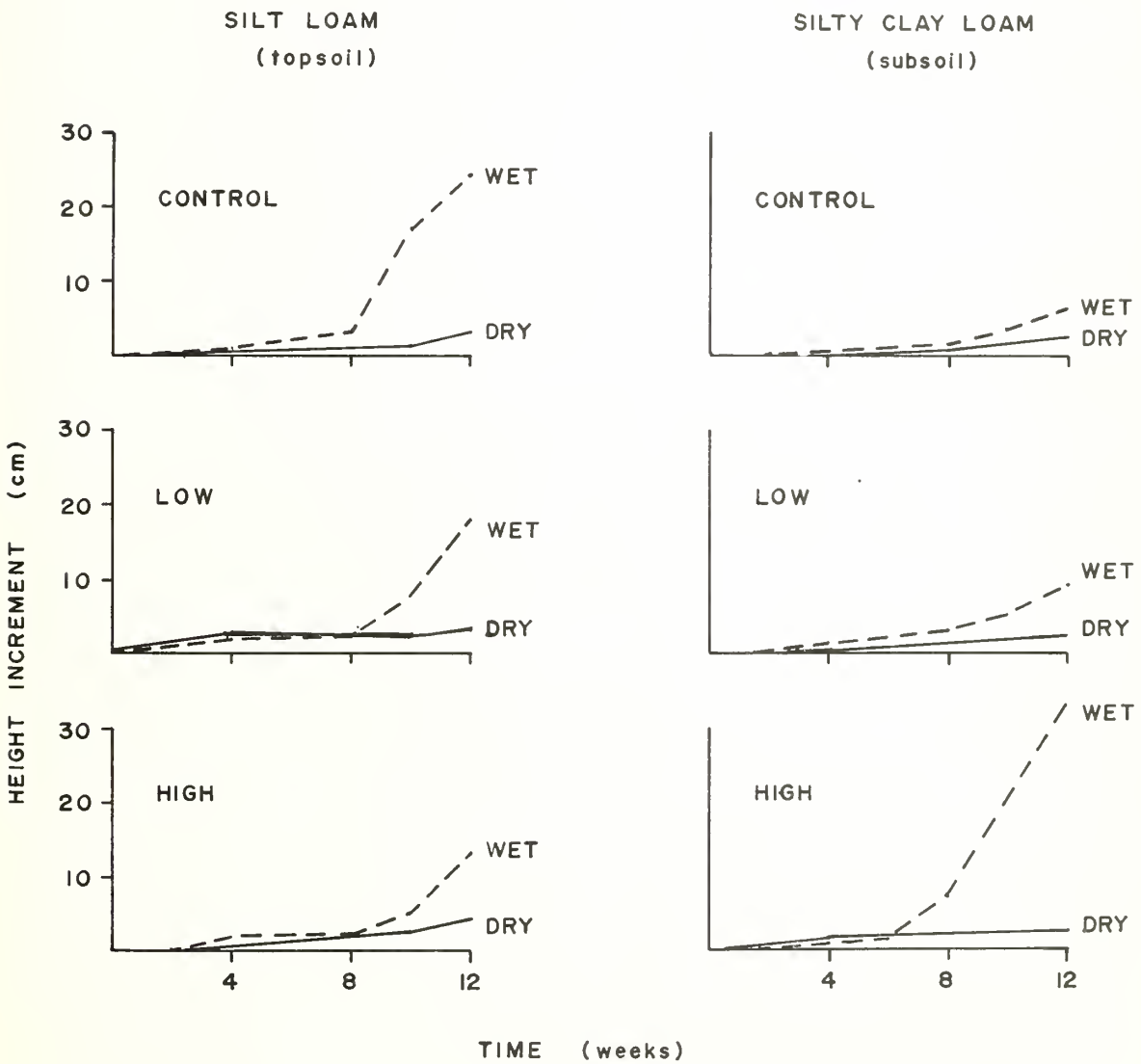
Height and height increments

Seedling height growth was related to water regime and to interactions of water, soil horizon, and fertility (Table 5 and Fig. 1).

Height growth was only 2 to 4 cm for seedlings in the dry treatments, but between 6 and 32 cm in the wet. Height growth was enhanced by fertilization when water was adequate, but fertilization without sufficient water tended to depress height growth. Among the wet treatments, the best height growth was on soil with fertility levels between 48 and 73 ppm phosphorus and 102 and 162 ppm potassium. Concentrations above or below these levels depressed growth even when water was plentiful.

Nitrogen is evaluated separately in this work because available nitrogen in the soil is highly variable. The best growth was obtained with soil nitrogen at the highest level, 50 ppm. As with the other nutrients, the best height growth was the result of the wet treatment and high fertility level.

Figure 1.—Cumulative height increment of red maple seedlings in two soil horizons, under two water regimes (wet or dry) and three fertility levels (control, low, and high).



Dry weights

Dry weights of stems, foliage, and roots were affected by water regime (Tables 3 and 4). Water was a significant factor for all the various plant parts measured, but fertility levels and interactions were also significant for some variables. The interactions are probably related to the chemical reactions and the proportion of clay in the soil, and to the quantity of water present—in much the same way that these factors influenced height growth. Under dry conditions, fertilization had only slight effects on stem, root, or foliage weight. With the moisture treatments, however, the responses varied within different plant parts (Table 4).

Seedlings on topsoil with low fertilization and on subsoil with high fertilization had the maximum total dry weights. These weights correspond to nutrient levels of 25 ppm nitrogen, 76 ppm phosphorus, and 101 ppm potassium in the topsoil and 50 ppm nitrogen, 48 ppm phosphorus, and 162 ppm potassium in the subsoil. Stem weights and foliage weights followed the same pattern.

There was maximum root growth in topsoil with the low fertility treatment. Root growth in the subsoil was greatest in the control treatment; in fact, maximum root growth for all treatments was in this soil with the lowest fertility.

Top/root ratio

Top/root ratio on a dry weight basis has been used as a measure of seedling balance. The interpretation of this ratio is not precise because it varies with species and seedling size. In our experiment, there were high top/root ratios when top growth was enhanced and root development inhibited. On the heavily fertilized and watered subsoil, the ratio was 2.19; for all the other treatments, it ranged from 0.91 to 1.50. Heavy fertilization in these soils could be detrimental to the tree under drought conditions.

Foliar nutrient levels

Foliar nutrient levels in the red maple seedlings (Table 5) were compared to measured growth variables using multiple regression analysis. Equations derived for the topsoil were not significant at $p \geq 0.8$. However, total height, total dry weight, and foliage weight did have a significant relationship to foliar nutrient levels in the subsoil where:

$$\text{Height} = 124.4 - 4.48\,(N\%) - 79.46\,(P\%) + 50.79\,(K\%) + 21.07\,(Ca\%) + 0.9222\,(Mg\%) - 0.1224\,(Mn\ ppm) - 0.0759\,(Fe\ ppm),\ R^2 = 0.923$$

$$\text{Total Weight} = 350.3 + 8.32\,(N\%) - 87.89\,(P\%) - 23.51\,(K\%) - 0.023\,(Ca\%) - 25.53\,(Mg\%) - 0.4464\,(Mn\ ppm) - 0.1766\,(Fe\ ppm),\ R^2 = 0.926$$

and

$$\text{Foliage Weight} = 54.9 + 2.26\,(N\%) - 16.25\,(P\%) - 1.14\,(K\%) - 0.366\,(Ca\%) + 0.501\,(Mg\%) - 0.0848\,(Mn\ ppm) - 0.0211\,(Fe\ ppm),\ R^2 = 0.939$$

The levels of foliar nutrients may be poorly related to growth. Stone and Christenson (1975) for example, concluded that foliar nutrients may be distributed throughout the biomass of a rapidly growing sugar maple (*Acer saccharum* Marsh.). Thus rapid growth may mask any relationship between optimum foliar nutrient levels for long-term growth and measured levels at a single time during tree growth.

Manganese was the nutrient common to all the regression equations. The prominence of manganese in these equations suggests that a Mn deficiency may have limited the growth in the subsoil. But because both manganese and iron were significant in two regression equations, another possibility is that a manganese-iron antagonism may have existed.

CONCLUSIONS

Although this study was designed to examine the optimum fertility levels for red maple, the interactions of soil moisture and soil fertility were also shown. For red maple seedlings on these soils, any growth enhancement through fertilization required high soil moisture content. Even modest water potentials, −3 bar, reduced both top and root growth.

With water readily available in these soils, seedling growth of both root and top was improved by the low level of fertilization—that is, roughly 25 ppm nitrogen, 25 to 75 ppm phosphorus, and 75 to 100 ppm potassium available in the soil. Available nutrients exceeding these quantities accelerated top growth, but tended to depress root growth. For similar soils and species we would not recommend heavy fertilization—soil nitrogen greater than 50 ppm, available phosphorus greater than 100 ppm, and available potassium greater than 150 ppm—unless accelerated top growth is the primary objective and the seedlings have an assured water supply. In that case, continued care would be necessary since greater shoot and leaf growth could subject the trees to moisture stress during drought periods.

Only three significant correlations were found between foliar nutrient levels and growth variables. Foliar nutrient levels that resulted in the greatest growth and the best top/root balance were in the low fertility treatment. This suggests that foliar nutrient levels of at least 2.6 percent N, 0.17 percent P, 0.6 percent K, 1.2 percent Ca, 0.4 percent Mg, 384 ppm Mn, and 212 ppm Fe indicate adequate tree nutrition.

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Basidiomycetes Associated with Decay of Living Oak Trees

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ABSTRACT

Thirty-one identified species of wood-rotting hymenomycetes were associated with decay and cull in upland oak stands in Illinois, Indiana, Kentucky, Missouri, and Ohio. Seven of these species produced brown rots that accounted for a volume loss of approximately 381 ft^3 in the trees sampled. The remaining species produced white rots that were associated with a volume loss of 557 ft^3. *Stereum frustulatum, Inonotus andersonii, Polyporus compactus, S. gausapatum,* and *Phlebia chrysocrea* were the most frequently encountered species, accounting for 70 percent of the white rot infections; 79 percent of the brown rot infections were caused by *Laetiporus sulphureus, Poria oleracea,* and *P. cocos.* Together, these brown and white rot fungi (excluding *P. oleracea* and *Phlebia chrysocrea*) were associated with 61 percent of the volume of decay. *Laetiporus sulphureus* caused more butt rot—and more decay—than any other fungus. *Inonotus andersonii* caused more trunk rot than any other fungus.

INTRODUCTION

THE PURPOSE of this study is to provide the pathological and mycological information on decay in upland oak forests in the central United States.

Early papers on heart-rotting fungi of oak by von Schrenk and Spaulding (1909), Hedgcock (1912), Hedgcock and Long (1914), and Long (1915) were based on local studies or on scattered observations of fruiting bodies and types of rot found. More recent lists of fungi common on oak published by Hepting (1935, 1941), Hepting and Hedgcock (1937), Roth and Sleeth (1939), and Genaux and Kuenzel (1939) included numerous species not mentioned in earlier publications. In 1942, Davidson et al. (1942) published pure-culture descriptions of 49 species of fungi isolated from decay in living oak species from widely separate localities. A study of decay after fire injury to southern bottomland hardwoods (Toole 1959) showed that more than 30 species of fungi caused decay. Toole isolated and identified 24 species of fungi from red oaks. Berry (1969) found 22 fungal species associated with decay in even-aged oak stands in Kentucky, and Berry and Beaton (1972) isolated and identified 29 species of fungi from oaks in the Central Hardwoods Region.

STUDY AREAS AND METHODS

From 1962 through 1968, decay was studied in even-aged, undisturbed (except by fire) upland oak stands—20 to 120 years old—in Illinois, Indiana, Kentucky, Missouri, and Ohio. Sample areas consisted of concentric circular plots 1/20-, 1/10-, and 1/5-acre in size. All living trees 3.6 inches in diameter at breast height (dbh) and larger were cut on the 1/20-acre plots; trees 5.6 inches in dbh and larger were cut on the 1/10-acre plots; and trees 11.6 inches in dbh and larger were cut on the 1/5-acre plots. Data collected from trees on the 1/20- and 1/10-acre plots were weighted so that all computations were based on 1/5-acre. Most of the 150 sample areas were on national or state forests. The results reported in this paper are based on dissections of approximately 3,000 oak trees on these plots.

After the trees were felled, the main stem and merchantable branches were cut into 4-foot bolts and examined for decay. The extent of decay was determined by splitting the bolt longitudinally. The maximum diameter of each decay column in the heartwood was located, diagramed, and recorded. The length of a decay column was measured from the maximum diameter—in each direction—and recorded to the nearest one-half foot.

Most of the decay fungi that attack oak rarely produce fruiting bodies on living trees, nor was it usually possible to diagnose the casual fungus from the type of decay alone. Therefore, to identify the fungi isolated from decay columns, it was necessary to compare pure cultures of these unidentified isolates with isolates from sporophores maintained in the reference collection of cultures at the Center for Forest Mycology Research at Madison, Wisconsin. Samples of decayed wood, each about 1 foot long, were split to expose a fresh face of infected wood. Six cores of wood, each about 4 mm in diameter, were extracted with a sterilized increment hammer and placed in test tubes containing 2.5 percent Fleischmann's diamalt[1] with 2 percent agar. If a decay organism was not isolated on the first attempt, a reisolation was attempted. All isolations of the same fungus from one sample were considered as one infection.

After the fungi had grown sufficiently in test tubes, the cultures were shipped to the Center for Forest Mycology Research for identification. About 95 percent of the decay fungi isolated from oak in this study were identified after their cultural characteristics were compared with those of identified isolates (Davidson et al. 1942).

Many of the decay columns did not yield basidiomycetous fungal isolates; however, some

[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

of the columns yielded bacteria and non-basidiomycetes. The non-basidiomycete fungi most commonly isolated from oak, in order of frequency, were: *Margarinomyces* sp., *Gliocladium* sp., *Phialophora* sp., *Trichocladium* sp., and *Paecilomyces* sp. The close association of bacteria, non-basidiomycetes, and basidiomycetes suggests that all are important in the decay process (Shigo 1967).

RESULTS

The fungi

A total of 31 species of fungi were associated with decay in oaks (Table 1). These fungi are hymenomycetes in the families Corticiaceae, Hericiaceae, Hymenochaetaceae, Polyporaceae, Steccherinaceae, Steraceae, and Tricholomataceae.

Of the species of basidiomycetes associated with decay, *Pleurotus sapidus* and *Rigidoporus vitreus* were isolated from only two trees each, and *Fistulina hepatica, Inonotus cuticularis, Poria inflata, Scytinostroma galactinum,* and *Spongipellis fissilis* were isolated from single trees (Table 2).

In earlier studies, *Phellinus everhartii* and *Inonotus hispidus* were thought to be common decay fungi in oak. However, these species were not isolated from our samples. Davidson et al. (1942) also reported that these fungi were seldom isolated from decay samples.

Poria mutans, which was isolated from scarlet and black oak, had not been previously reported on oak. An authenicated basidiocarp specimen and culture of this fungus species from oak is in the collections of the Center for Forest Mycology

Table 1. Basidiomycetes occurring on living oak in the Central Hardwood Region

Family CORTICIACEAE
Phlebia chrysocrea (Berk. & Curt. in Berk.) Burds. ("Unknown H" of earlier publications)
Scytinostroma galactinum (Fr.) Donk (= *Corticium galactinum* (Fr.) Burt)
Family HERICIACEAE
Hericium erinaceus (Bull. ex Fr.) Pers. (= *Hydnum erinaceus* Bull. ex Fr.)
Hericium spp. (not identified to species)
Family HYMENOCHAETACEAE
Hymenochaete rubiginosa Dicks. ex Lév.
Inonotus andersonii (Ell. & Ev.) Černý (= *Poria andersonii* (Ell. & Ev.) Neuman)
Inonotus cuticularis (Bull. ex Fr.) Karst. (= *Polyporus cuticularis* Bull. ex Fr.)
Inonotus dryophilus (Berk.) Murr. (= *Polyporus dryophilus* Berk.)
Family POLYPORACEAE
Bjerkandera adusta (Wild. ex Fr.) Karst. (= *Polyporus adustus* Willd. ex Fr.)
Coriolus versicolor (L. ex Fr.) Quél. (= *Polyporus versicolor* L. ex Fr.)
Fistulina hepatica (Huds.) Fr.
Laetiporus sulphureus (Bull. ex Fr.) Bond. & Sing. (= *Polyporus sulphureus* Bull. ex Fr.)
Merulius tremellosus Schrad. ex Fr.
Polyporus compactus Overh.
Polyporus frondosus Dicks. ex Fr.
Poria cocos (Schw.) Wolf
Poria inflata Overh.
Poris mutans Pk.
Poria nigra (Berk.) Cke.
Poria oleracea Davidson & Lombard
Rigidoporus vitreus (Pers. ex Fr.) Donk
Spongipellis fissilis (Berk. & Curt.) Murr. (= *Polyporus fissilis* Berk. & Curt.)
Spongipellis pachyodon (Pers.) Kotl. & Pouz. (= *Irpex mollis* Berk. & Curt.)
Spongipellis unicolor (Schw.) Murr. (= *Polyporus obtusus* Berk.)
Tyromyces spraguei (Berk. & Curt.) Murr. (= *Polyporus spraguei* Berk. & Curt.)
Family STECCHERINACEAE
Steccherinum setulosum (Berk. & Curt.) L. W. Miller
Family STEREACEAE
Stereum complicatum (Fr.) Fr. (= *Stereum rameale* (Schw.) Burt)
Stereum frustulatum (Pers. ex Fr.) Fckl.
Stereum gausapatum (Fr.) Fr.
Stereum subpileatum Berk. & Curt.
Family TRICHOLOMATACEAE
Armillariella mellea (Vahl ex Fr.) Karst. (= *Armillaria mellea* (Vahl ex Fr.) Quél.)
Pleurotus sapidus (Schulz. in Kalchb.) Sacc.

Table 2. Number of infections by identified white-rot and brown-rot fungi in living oak, by host species

Fungus species	Scarlet oak	Black oak	Northern red oak	White oak	Chestnut oak	Total	Percent
			WHITE-ROT FUNGI				
Stereum frustulatum	73	35	4	12	6	130	14.0
Inonotus andersonii	13	58	3	38	13	125	13.5
Polyporus compactus	32	52	9	8	5	106	11.4
Stereum gausapatum	37	30	4	10	8	89	9.6
Phlebia chrysocrea	47	3	3	10	2	65	7.0
Spongipellis pachyodon	2	26	1	17	7	53	5.7
Hericium erinaceus	4	14		22	3	43	4.6
Armillariella mellea	4	3		4	4	15	1.6
Merulius tremellosus	4	6		2	3	15	1.6
Spongipellis unicolor	2	3		8	2	15	1.6
Inonotus dryophilus	4			2	7	13	1.4
Coriolus versicolor	3	7	1	2		13	1.4
Stereum complicatum		3		4	3	10	1.1
Hymenochaete rubiginosa	8	1				9	1.0
Poria mutans	3	4				7	.8
Steccherinum setulosum		5		2		7	.8
Hericium spp.				6		6	.7
Polyporus frondosus	3			2		5	.5
Bjerkanderi adusta		2			2	4	.4
Stereum subpileatum	2	1				3	.3
Pleurotus sapidus	2					2	.2
Rigidoporus vitreus					2	2	.2
Scytinostroma galactinum		1				1	.1
Inonotus cuticularis				1		1	.1
Spongipellis fissilis				1		1	.1
Total	243	254	25	151	67	740	79.7
			BROWN-ROT FUNGI				
Laetiporus sulphureus	47	12	3	4	1	67	7.2
Poria oleracea	41	5	3			49	5.3
Poria cocos	6	17	2	2	7	34	3.6
Tyromyces spraguei	22	3	1			26	2.8
Poria nigra	7	4				11	1.2
Fistulina hepatica	1					1	.1
Poria inflata		1				1	.1
Total	124	42	9	6	8	189	20.3
All species	367	296	34	157	75	929	100.0

Research. Also, *Steccherinum setulosum,* which was isolated from black and white oak, had not been previously reported isolated in a decay survey.

The most frequently isolated species, in order of frequency, were: *Stereum frustulatum, Inonotus andersonii, Polyporus compactus, S. gausapatum, Laetiporus sulphureus, Phlebia chrysocrea, Spongipellis pachyodon, Poria oleracea, Hericium erinaceus, P. cocos,* and *Tryomyces spraguei.* Brief descriptions of these fungal species, which accounted for 85 percent of the identified infections, follow.

Stereum frustulatum—Causes a white pocket rot known as "partridge wood"; the small, spindle-shaped pockets are lined with white mycelium. The sporophores, less than 1 inch long, are flat, raised, and dirty white. In culture, *S. frustulatum* resembles *S. subpileatum* but may be distinguished by its faster growth rate, lighter orange mat, and consistent negative oxidase reaction (Davidson et al. 1942).

Inonotus andersonii—Causes a white spongy rot. The bright orange sporophores develop under the bark of dead trees and downed logs, eventually rupturing these tissues and becoming exposed. In culture, *I. andersonii* is characterized by its mustard-colored-to-brown mat, short, bulbous, brown setae, and positive oxidase reaction (Davidson et al. 1942).

Polyporus compactus—Causes a white rot. The creamy white to light tan, mostly resupinate sporophores can fruit over large areas of the host. In culture, *P. compactus* is distinguished by its fast growing white mat with scattered yellow abortive poroid areas, abundant chlamydospores, and positive oxidase reaction (Davidson et al. 1942).

Stereum gausapatum—Causes a white pocket or white mottled rot. The small, thin, slightly shelf-shaped sporophores develop abundantly on old stumps and slash. Decay is particularly prevalent in sprout stands because the fungi invade the heartwood of the sprouts from the decay in old stumps. In culture, the species develops a buff-colored mat, single and multiple clamp connections, and dark brown exudation droplets on gallic acid agar. The oxidase reaction is positive. It can be distinguished from cultures of *S. complicatum,* which are faster growing and lack the exudation droplets (Davidson et al. 1942).

Laetiporus sulphureus—Commonly called the sulphur fungus, causes a brown cubical rot. The shelf-like sporophores are orange on the upper surface (with a sulphur-yellow undersurface when fresh), weathering to a dirty white. They frequently overlap to form large rosette-like clusters, and may occur on the tree trunk or on the ground at the base of the tree. In culture, the species is characterized by its pink fast-growing mat, lack of clamp connections, abundant chlamydospores, and negative oxidase reaction (Davidson et al. 1942).

Phlebia chrysocrea—Previously misidentified as *Corticium lividum* Pers. ex Fr. (Davidson et al. 1942). It was later designated "Unknown H" until correctly identified in 1975 (Lombard and Burdsall 1975). This fungus causes a white mottled or small pocket rot, the wood being reduced to a white fibrous mass with bright yellow mycelial deposits in advanced stages of decay. In culture, *P. chrysocrea* develops a white mat with scattered areas of bright yellow mycelium that turns purple when touched with KOH solution, and emits a strong carbide odor. The oxidase reaction is positive (Davidson et al. 1942; Lombard and Burdsall 1975).

Spongipellis pachyodon—Causes a white spongy heart rot. After becoming established in the heartwood, the fungus attacks living sapwood and the cambium, causing irregular rough cankers to develop on the tree trunk. Well-developed mature sporophores of *S. pachyodon* are conspicuously toothed, while those of *S. unicolor* are poroid. In culture, isolates of these species are so similar that they could not be differentiated in previous studies (Davidson, et al. 1942, as *Irpex mollis* and *Polyporus obtusus*). In the present study, cultures of *S. pachyodon* were faster growing at high temperatures, and the two species were readily differentiated by mat diameter after 4 days' growth at 35° C. The culture of each species is characterized by a moderately fast-growing white mat, abundant chlamydospores, and positive oxidase reaction (Davidson et al. 1942).

Hericium erinaceus—Commonly called the hedgehog fungus, causes a white piped or pocket rot in the early stages; the wood decomposes completely, leaving large hollows lined with pale yellow mycelium in advanced stages. The soft annual sporophores are white (turning pale yellow or pale brown with age) and globular, with a hairy pilear surface and long slender teeth on the lower surface. In culture, this species is characterized by a medium growth rate, white appressed mat, hyphae with end cells of coarsely granular contents, chlamydospores, and positive oxidase reaction (Davidson et al. 1942).

Poria oleracea—Causes a brown cubical rot. The creamy white sporophores are resupinate and inconspicuous and are often found on down dead trees. In culture, *P. oleracea* is characterized by a white mat, odor of rotten cabbage (in old cultures), abundant chlamydospores, and negative oxidase reaction (Davidson et al., as *Poria* sp.).

Poria cocos—Causes a brown root and butt rot. The creamy-white sporophores may be found on slash, down trees, roots, etc. The fungus also forms large oblong to subglobose sclerotia (known as "tuckahoes") in the soil. In culture, the fast-growing pale pink mat, the very large hyphae and inflated cells, and the negative oxidase reaction are characteristic of the species.

Tyromyces spraguei—Causes a friable brown rot. The sporophores are annual, slightly bracket-shaped, and can be as much as 6 inches wide. In culture, *T. spraguei* develops a fast growing white

[illegible] and brown-rot fungi in living oak, by infection entry court.

Fungus species	Unsound branch stub	Fire scar	Closed branch bump	Insect wound	Sound branch stub	Parent stump	Damaged or dead top	Mechanical injury	Root	Open branch bump	Miscella-neous	Total
					WHITE-ROT FUNGI							
Stereum frustulatum	26	7	5	7	52	5	9	9	4	5	1	130
Inonotus andersonii	41	6	44	5	1	4	6	5	1	9	3	125
Polyporus compactus	21	7	6	31	2	2	5	12	—	6	14	106
Stereum gausapatum	21	4	3	—	13	14	24	4	1	2	3	89
Phlebia chrysocrea	4	5	7	14	4	14	—	7	3	2	5	65
Spongipellis pachyodon	6	3	13	—	3	—	—	9	6	6	7	53
Hericium erinaceus	5	17	4	6	—	3	—	5	3	—	—	43
Armillariella mellea	—	12	—	—	—	1	—	—	2	—	—	15
Merulius tremellosus	1	9	—	5	—	—	—	—	—	—	—	15
Spongipellis unicolor	10	—	—	—	—	—	—	—	5	—	—	15
Inonotus dryophilus	9	—	—	—	—	—	2	—	—	2	—	13
Coriolus versicolor	3	—	4	—	—	—	4	1	—	—	1	13
Stereum complicatum	1	—	—	3	—	3	3	—	—	—	—	10
Hymenochaete rubiginosa	2	—	1	—	5	—	—	—	—	—	1	9
Poria mutans	4	—	—	3	—	—	—	—	—	—	—	7
Steccherinum setulosum	—	7	—	—	—	—	—	—	—	—	—	7
Hericium spp.	—	2	—	2	—	2	—	—	—	—	—	6
Polyporus frondosus	—	—	—	—	—	—	—	—	5	—	—	5
Bjerkanderi adusta	—	3	1	—	—	—	—	—	—	—	—	4
Stereum subpileatum	—	—	1	—	1	1	—	—	—	—	—	3
Pleurotus sapidus	—	—	—	2	—	—	—	—	—	—	—	2
Rigidoporus vitreus	—	—	2	—	—	—	—	—	—	—	—	2
Scytinostroma galactinum	—	—	1	—	—	—	—	—	—	—	—	1
Inonotus cuticularis	—	1	—	—	—	—	—	—	—	—	—	1
Spongipellis fissilis	—	—	—	—	—	—	—	—	—	1	—	1
Total	154	83	92	78	81	49	53	52	30	33	35	740
					BROWN-ROT FUNGI							
Laetiporus sulphureus	5	18	14	5	—	4	—	1	4	5	11	67
Poria oleracea	6	2	1	7	5	4	13	1	—	4	6	49
Poria cocos	—	16	—	—	—	10	—	—	8	—	—	34
Tyromyces spraguei	1	2	—	—	—	13	—	—	7	—	3	26
Poria nigra	2	2	—	—	2	—	2	—	2	1	—	11
Fistulina hepatica	—	1	—	—	—	—	—	—	—	—	—	1
Poria inflata	—	1	—	—	—	—	—	—	—	—	—	1
Total	14	42	15	12	7	31	15	2	21	10	20	189
All species	168	125	107	90	88	80	68	54	51	43	55	929

mat, abundant chlamydospores, and fiber hyphae. The oxidase reaction is negative.

Host species

The 31 species isolated and identified as causing decay in oak were associated with one or more of the following species: scarlet oak (*Quercus coccinea* Muenchh.); black oak (*Q. velutina* Lam.); northern red oak (*Q. rubra* L.); white oak (*Q. alba* L.); and chestnut oak (*Q. prinus* L.). The frequency of infection by these fungi for each oak species is shown in Table 2.

Most of these fungi exhibited very little preference for a particular oak species. However, the following fungi were confined to species in the red oak group: *Poria oleracea* (49 infections); *Tyromyces spraguei* (26 infections); *P. nigra* (11 infections); *Hymenochaete rubiginosa* (9 infections); and *P. mutans* (7 infections). With the exception of *P. mutans,* these fungi have been reported previously from the white oak group (U. S. Department of Agriculture 1960).

Entry courts

Fungi that cause decay in the heartwood in live standing trees require an infection court that directly or indirectly provides access to the heartwood. The apparent avenues of entrance of the decay fungi are shown in Table 3. Basal wounds from fire and branch stubs and wounds caused by normal death of limbs are the most common sites of infection. Unsound branch stubs and fire scars were associated with about one-third of all identified infections.

The fungal species most frequently isolated entered the heartwood through three or more entry courts. However, 60 percent of the infections caused by *Stereum frustulatum* were associated with branch stubs. Branch stubs also were associated with more than one-third of the infections by the following white-rot species: *Inonotus andersonii, I. dryophilus, Hymenochaete rubiginosa, Spongipellis unicolor,* and *Stereum gausapatum* Fire scars were important entry courts for the brown rotters *Laetiporus sulphureus* and *Poria cocos,* and for the following white-rot fungi: *Armillariella mellea, Bjerkandera adusta, Hericium erinaceus, Merulius tremellosus,* and *Steccherinum setulosum.*

Infections by *Phlebia chrysocrea, Poria cocos,* and *Tyromyces spraguei* commonly occurred through parent stumps. Although *Stereum gausapatum* frequently entered through parent stumps, the majority of infections by this species were associated with damaged or dead tops.

Decay

Decay may be designated as "brown rot" or "white rot" according to the color or character of the decay. The brown rots include those in which the cellulose and associated polysaccharides of the cell wall are attacked and the decayed wood turns a shade of brown. When a greater proportion of lignin is broken down, the color of the decayed wood becomes lighter; these rots are known as white rots. Almost 80 percent of the fungi isolated from oak were white rotters; these fungi accounted for a volume loss of 556 ft^3 (Table 4). Although brown-rot fungi are not as numerous as white-rot fungi in oaks, the brown rotters nevertheless accounted for a volume loss of 381 ft^3.

Depending on its position in the tree, decay in living trees may also be classified as trunk rot or as butt and root rot. Most of the wood-decay fungi isolated from oak can cause both types of rot. However, some species, for example, *Armillariella mellea, Poria cocos,* and *Tyromyces spraguei,* caused rot only in the roots and butt.

Although the number of root and butt infections was less than half the number of trunk infections, the former accounted for a greater volume of decay, 508.61 ft^3 compared to 428.21 ft^3.

On the basis of cubic feet of decay, the fungi associated with the most serious losses were *Inonotus andersonii, Laetiporus sulphureus, Polyporus compactus, Poria cocos, Stereum gausapatum,* and *S. frustulatum. Laetiporus sulphureus* was associated with more butt rot (103.80 ft^3) than any other fungus; *I. andersonii* was the most destructive trunk-rot fungus (71.48 ft^3).

The volume of decay varies greatly between trees of the same species, size, age, and between trees with similar injuries. This variation may be due to the individual characteristics of each fungal species. For example, fungi of one group, typified by *Armillariella mellea,* confine their activity almost entirely to the roots and butts of trees, and rarely extend more than a few feet up into the trunk. Those of another group, typified by *Laetiporus sulphureus* and *Hericium erinaceus,* may enter at the butt or through some wound in the top, and are capable of producing extensive rot throughout the tree. Those of a third group, including *Stereum frustulatum* and *Inonotus andersonii,* are primarily top or upper trunk-in-

habiting species; these fungi rarely extend down to the butt.

Stem and butt rots cause considerable loss in both timber volume and quality in oak forests. These losses can be reduced by forest management practices that prevent wounding, ensure proper handling of sprout stands, maintain adequate stocking densities, and provide for the proper selection of crop trees.

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Table 4. Relationship between infection by identified white-rot and brown-rot fungi in living oak and the portion of the tree bole affected.

Fungus species	Number of infections			Decay volume(ft^3)		
	In butt[a]	In trunk	Total	In butt[a]	In trunk	Total
			WHITE-ROT FUNGI			
Stereum frustulatum	27	103	130	19.68	61.86	81.54
Inonotus andersonii	15	110	125	22.61	71.48	94.09
Polyporus compactus	12	94	106	19.65	40.83	60.48
Stereum gausapatum	22	67	89	28.44	56.14	84.58
Phlebia chrysocrea	27	38	65	17.78	13.26	31.04
Spongipellis pachyodon	1	52	53	11.78	28.87	40.65
Hericium erinaceus	26	17	43	36.73	4.20	40.93
Armillariella mellea	15	—	15	17.18	—	17.18
Merulius tremellosus	9	6	15	18.80	3.37	22.17
Spongipellis unicolor	6	9	15	.77	5.42	6.19
Inonotus dryophilus	1	12	13	6.38	17.77	24.15
Coriolus versicolor	2	11	13	8.45	2.45	10.90
Stereum complicatum	2	8	10	.34	.70	1.04
Hymenochaete rubiginosa	—	9	9	—	2.11	2.11
Poria mutans	3	4	7	2.15	1.73	3.88
Steccherinum setulosum	7	—	7	3.74	10.48	14.22
Hericium spp.	3	3	6	4.31	.47	4.78
Polyporus frondosus	5	—	5	3.58	—	3.58
Bjerkanderi adusta	3	1	4	4.04	.05	4.09
Stereum subpileatum	1	2	3	2.18	1.06	3.24
Pleurotus sapidus	—	2	2	—	.04	.04
Rigidoporus vitreus	—	2	2	—	.14	.14
Scytinostroma galactinum	—	1	1	—	.51	.51
Inonotus cuticularis	1	—	1	2.98	—	2.98
Spongipellis fissilis	1	—	1	1.77	—	1.77
Total	189	551	740	233.34	322.94	556.28
			BROWN-ROT FUNGI			
Laetiporus sulphureus	35	32	67	103.80	67.48	171.28
Poria oleracea	10	39	49	30.43	13.50	43.93
Poria cocos	34	—	34	86.42	—	86.42
Tyromyces spraguei	26	—	26	29.86	—	29.86
Poria nigra	4	7	11	8.62	24.29	32.91
Fistulina hepatica	1	—	1	2.67	—	2.67
Poria inflata	1	—	1	13.47	—	13.47
Total	111	78	189	275.27	105.27	380.54
All species	300	629	929	508.61	428.21	936.82

[a] Decay originating at stump height or below was considered butt decay.

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RECORDS OF BACKCOUNTRY USE CAN ASSIST TRAIL MANAGERS

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Abstract

Records of recreational use of Eastern backcountry areas have not been systematically kept by many trail management groups in the past. Decisions on backcountry site designs and facilities should not be made without information on visitor use and behavior. An analysis of sample data from records of overnight shelter use on the Long Trail, Vermont, indicates how such information may be used by trail managers.

INTRODUCTION

THE LEISURE TIME and income of many Americans have been increasing since the 1950's. Coincident with the country's higher standard of living has been a decline in the physical quality and availability of undeveloped land near metropolitan areas, where the majority of the population resides. Increasing numbers of people spend their leisure time in pursuit of recreational activities that take them away from the pressures of urban life and into the primitive environments of remote forest lands.

The mountainous lands of the Appalachian Highlands offer some of the most scenic and remote recreation sites in the East. The number of visitors to the trail systems in these mountains increased rapidly during the 1960's and early 1970's. Most of the backcountry trails and overnight facilities were constructed during the 1930's and were not designed to handle large number of visitors. Some of the more fragile sites have been adversely affected by the heavier visitor use. Some of the hiking trails have become severely eroded, and popular overnight sites have become denuded and congested with campers. Consequently, forest managers have been faced with the need to manage Eastern backcountry resources for a larger volume of dispersed recreationists.

Unfortunately, very little information has been collected to document the current use pattern of the forest visitors. Decisions on backcountry uses are being made without knowing how visitor use is distributed throughout the system or how visitor use at a specific site compares with the capacity of that facility. In this study, backcountry-use data have been taken from caretaker records of shelter sites on the Long Trail in Vermont to show how visitor-use information can be of help to managers who make decisions on site design. The types of information that can be gleaned from such records are presented in this paper.

THE GREEN MOUNTAINS

The Green Mountains form part of the Appalachian Highlands. The mountain range lies along a north-south axis through Vermont, extending from the Massachusetts line to the Canadian border. Formed about 350 million years ago, these mountains have undergone extensive weathering and erosion, and are now relatively low and rounded compared to the younger mountain ranges in the western United States. The highest peak, Mt. Mansfield, is 4,393 feet.

Hardwood forests of birch, beech, and maple on the lower slopes gradually grade into northern spruce-fir forests at elevations above 2,800 feet. Alpine tundra appears on the summits of two of the high peaks, Mt. Mansfield and Camel's Hump. These and most of the other high peaks lie in the northern section of the range. Within the southern section, several scenic ponds lie between the crests of lower mountains. The recreational attractions of each section are equally unique.

The Long Trail

In 1910 the Green Mountain Club (GMC) was formed by 23 men who were interested in constructing a trail that would run along the ridgeline of the Green Mountains. Permission was obtained from the various landowners to cut a trail through their lands and build shelters or use existing camps and farmhouses for overnight facilities. The trail was constructed section by section over a period of 21 years by GMC volunteers and State crews. During this time, 14 shelters were built. By 1931, a 263-mile trail traversed Vermont from Massachusetts to Canada (Fig. 1), passing over Vermont's highest mountain peaks and skirting several scenic mountain ponds. The trail was one of the earliest long-distance trails in the country, predating the Appalachian Trail, and was named The Long Trail (Green Mountain Club 1977).

Today, about half of the trail crosses private property. Fifteen percent of the trail passes

Figure 1.—Location of the Long Trail.

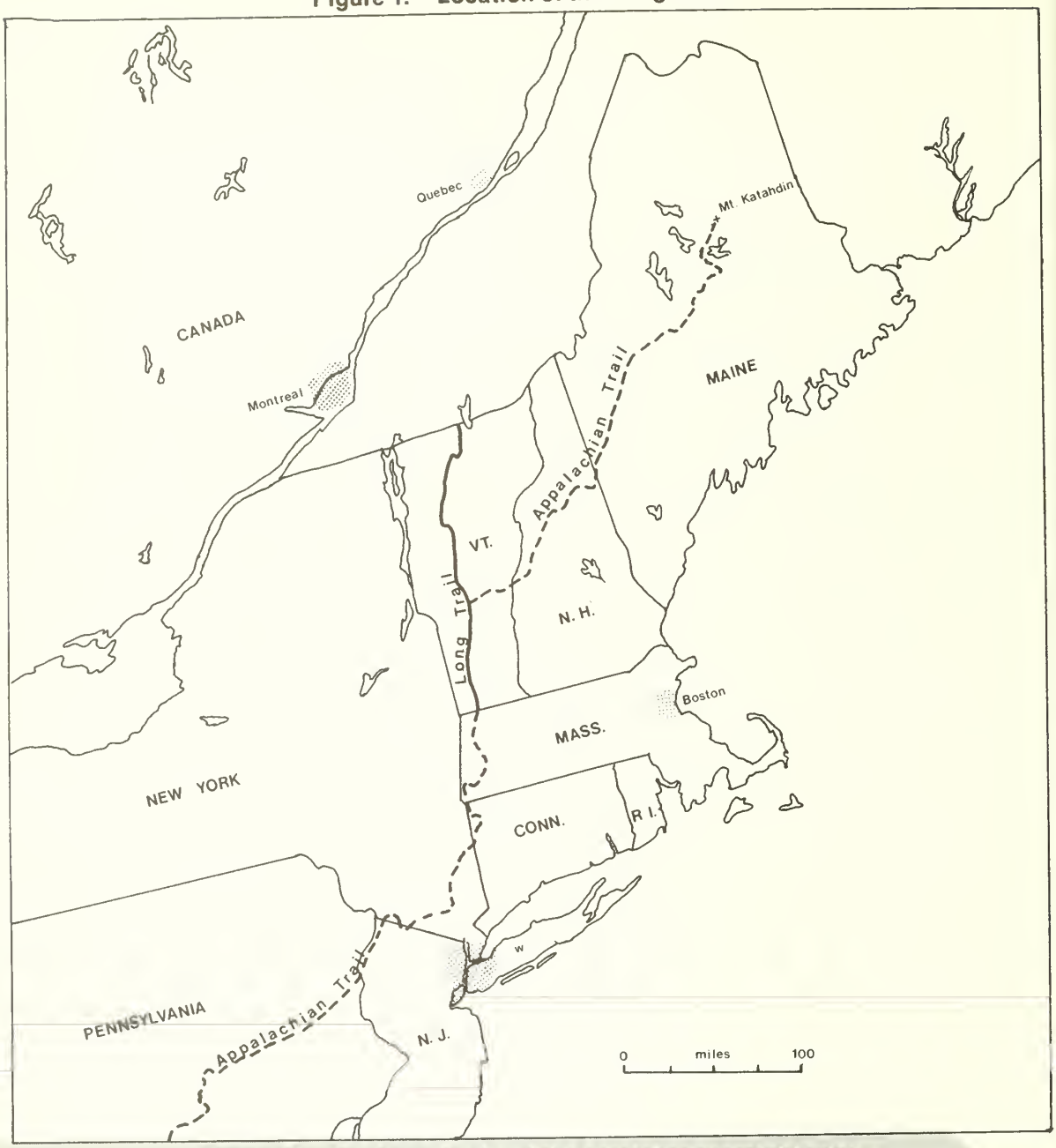
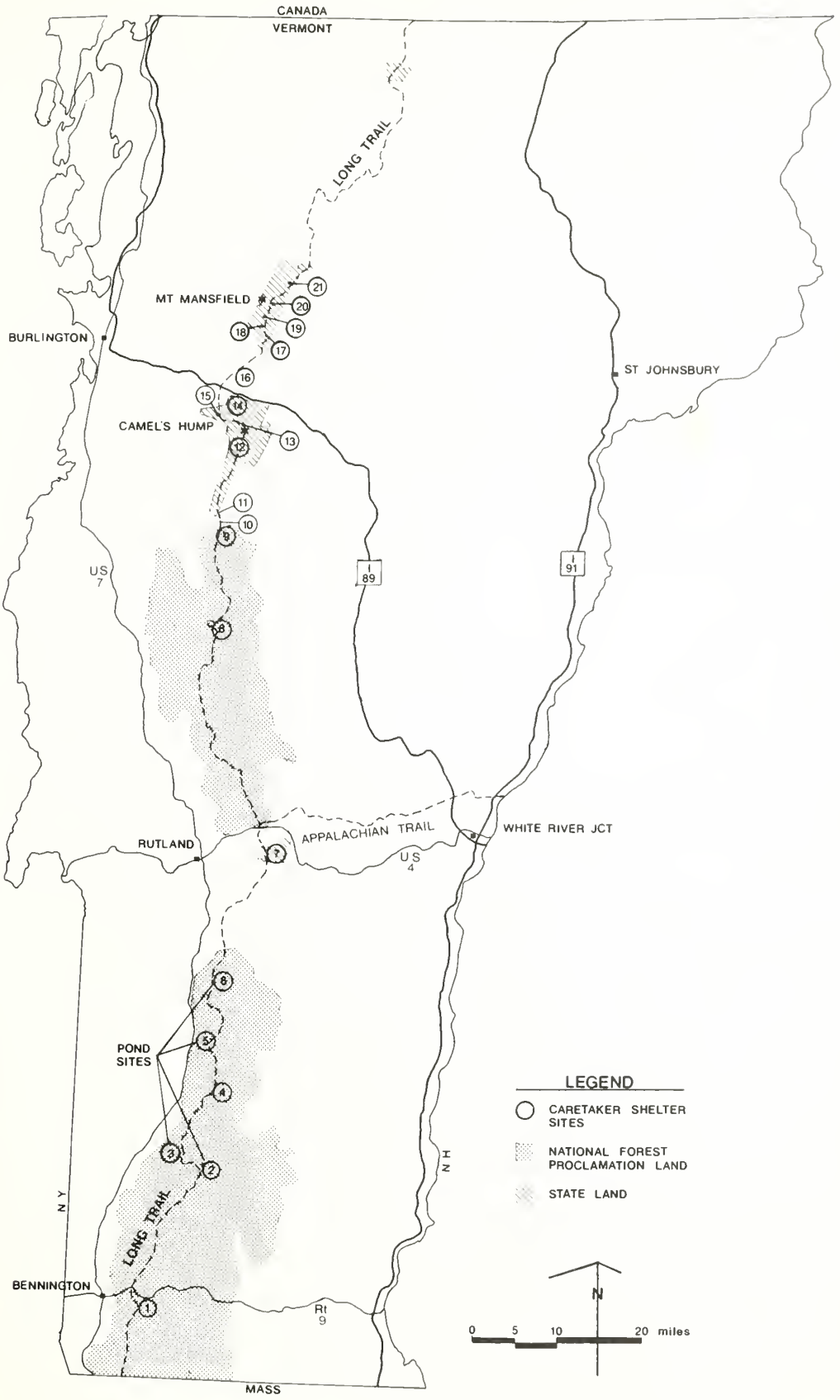


Figure 2.—The Long Trail and the caretaker overnight sites.

1. Congdon Camp
2. Stratton Pond
3. Bourn Pond
4. Bromley
5. Griffith Lake
6. Little Rock Pond
7. Cooper Lodge
8. Skyline Lodge
9. Castlerock
10. Glen Ellen Lodge
11. Stark's Nest
12. Montclair Glen
13. Gorham
14. Buchanan
15. Wiley
16. Bolton
17. Taylor
18. Twin Brooks Primitive Tentsite Area
19. Butler
20. Taft
21. Sterling Pond

THE LONG TRAIL



through State land, primarily in the northern section. The Green Mountain National Forest owns land on 40 percent of the trail, though the proclamation boundaries surround about 50 percent of the trail, as shown in Figure 2. Most of the National Forest proclamation land is a patchwork of Federal and private lands. The Appalachian National Scenic Trail, under the jurisdiction of the National Park Service, shares the southern section of the trail (about 97 miles) from the Massachusets border to U.S. 4 at the Sherburne Pass.

The Green Mountain Club continues to be the trail steward. The U.S. Forest Service and the State of Vermont work cooperatively with the club on those sections of the trail that pass through their lands. Multiple land ownership of the trail, however, has increased the complexity of managing the trail for overnight hikers. Camping regulations are different for different areas. On Federal land, tenting and campfires are allowed anywhere along the trail. Where the trail passes through State land, tenting and campfires have been prohibited without a special permit since 1971.[1] There is one exception to this rule: Tenting is permitted at the Long Trail shelter sites on State land when the shelters are full. Tenting on private land is not permitted without permission of the landowner.

Today, about 70 overnight shelter facilities are found along the trail at fairly evenly spaced sites about 4 miles apart. Most of the shelters on the northern section of the trail are enclosed structures with bunk and floor space for 8 to 12 people. Most of the shelters on the southern section of the trail are three-sided lean-to's which can accommodate six to eight people.[2]

The Green Mountain Club caretaker program

The Long Trail shelter facilities received relatively few recreational visitors before the 1960's. Increased interest in hiking and camping has changed that situation. Estimates from old register data indicate that shelter use was 3 to 15 times less than current use. Today, the trail is within a 1/2-day's drive of more than 53 million people. Use of off-road camping areas within the Green Mountain National Forest increased about two and one-half times between 1965 and 1972.[3]

The Green Mountain Club found it necessary to respond to the increased trail use. The club began an informal caretaker program at the most heavily visited sites to inform hikers of the fragility of some of the mountain environments. In 1969, an official program was started with two paid caretakers. The program expanded to 13 caretakers by 1972, then to about 21 caretakers by 1975 (Green Mountain Club 1975).

Individual caretakers live at assigned shelter sites from mid-June to the beginning of September. A few of the more popular sites retain caretakers until mid-October. The fees paid by the overnight visitors for the use of the shelters or tent platforms go directly to the caretakers. In addition, each caretaker receives a small stipend from the GMC to help cover expenses while living at the site.

Caretakers can conveniently and accurately observe and record visitor use at shelter sites (Fig. 2). Overnight visits have been recorded since 1970. The visitor records include the number of persons and organized groups using the shelters. In addition, overnight hikers are requested to register their residence, party size, trip duration, and the origin and destination points of their hiking trips. These records provide data that help us understand the fluctuations in use of the backcountry overnight facilities and some of the characteristics and preferences of the Long Trail population.

[1] During the 1960's, there was excessive long-term, roadside camping-cum-homesteading on State lands. This prompted the Vermont legislature to pass a law (State Act 86, 1971) prohibiting all tenting on State land. The State is now considering a modification of this law.

[2] Information on shelters and site conditions is from: (1) U. S. Forest Service, 1973. Shelter site inspection report, Appalachian-Long Trail system, plan of management. U. S. Dep. Agric. For. Serv., Green Mt. Natl. For. Append. 5 Office Rep. 94 p. (2) U. S. Forest Service. 1975. Long Trail status survey. U. S. Dep. Agric. For. Serv., Northeast. For. Exp. Stn., Durham, N. H. Office Rep.

[3] U. S. Forest Service. 1972. A plan of management, Appalachian-Long Trail system. U. S. Dep. Agric. For. Serv., Green Mt. Natl. For. Prelim. Office Rep. 33 p.

CHARACTERISTICS OF THE LONG TRAIL HIKERS

Information from trailhead self-registration boxes and caretaker observations indicates that day hikers represent the largest proportion of users on many parts of the trail. However, the difference between the numbers of day and overnight hikers cannot be determined from the available records as few day hikers register at a shelter site.

The sample of visitor records used for this paper pertains to overnight hikers. Of all the overnight hikers passing through caretaker sites in 1975 and 1976, 67 percent were on the trail for 2 to 5 days (short-distance overnight hikers) and 33 percent were on the trail for more than 5 days (long-distance overnight hikers). These proportions were similar for both the northern and southern sections of the trail.

Hiker residence

The Long Trail attracts hikers from all parts of the country, but the portion of in-state hikers using the trail is relatively small compared to the total out-of-state hikers (Table 1). Most of the short-distance hikers (64 percent) on the southern section of the trail come from the surrounding, more densely populated states—Massachusetts, New York, and Connecticut. The southern section is, of course, more conveniently located to the residents than the northern section. Vermont residents account for nearly half (43 percent) of the short-distance use on the northern section of the trail.

Most of the long-distance overnight hikers on the trail are from out of state. The proportion of long-distance hikers who come from non-New England States is higher in the southern section of the trail (33 percent) than in the northern section (16 percent), due, perhaps, to the use of the Appalachian Trail.

Group sizes

Hiking parties of more than 10 persons have been discouraged by all the Long Trail management groups since the early 1970's. The 1977 edition of the GMC Long Trail Guidebook now en-

Table 1.—Percentage of short- and long-distance overnight hikers from different states using the southern and northern section of the Long Trail, 1975

State	Short-distance hikers		Long-distance hikers		All hikers	
	Southern	Northern	Southern	Northern	Southern	Northern
In-State						
Vermont	19	43	10	16	16	36
Out-of-State						
Massachusetts	27	13	17	24	24	16
New York	19	7	18	18	19	10
Connecticut	18	6	14	14	17	8
R.I./N.H./Maine	4	3	4	3	4	3
Other U. S.	12	13	33	16	19	14
Canada	1	14	4	9	2	13
Total Out-of-state:	81	56	90	84	85	64

Table 2.—Percentage of short- and long-distance overnight hikers by size of party, 1974 and 1975

Hikers	1	2	3	4-6	7-10	10 or more
Short-distance	16.4	42.1	14.9	16.9	6.0	3.7
Long-distance	45.1	31.9	9.5	7.7	3.5	2.3

courages hikers to travel in groups of no more than four to six.

In the mid-1970's, the majority of the Long Trail hiking parties were of less than three persons (Table 2). Long-distance hikers tended to travel alone while short-distance hikers were most often in groups of two. A relatively small proportion of the hiking parties were composed of more than 10 persons.

Organized groups

Hiking groups of Scouts or from summer youth camps and school or community organizations have been regular users of the Long Trail. For each of the past 5 years, organized groups have accounted for slightly more than 25 percent of the total overnight visitors at the caretaker sites (Fig. 3).

During 1975 and 1976 organized groups could be found at a caretaker site on an average of 16 percent of the days in the summer season. However, the popular pond sites, Little Rock Pond and Stratton Pond, and the popular high-peak sites on Mt. Mansfield and Camel's Hump, were visited by organized groups more frequently (about 30 percent of the season). These groups used the shelter sites as much on weekdays as on weekends. Between 1974 and 1976 the average size of organized groups dropped from 12.7 to 10.5 persons and the percentage of organized groups of more than 10 persons dropped from 42 percent to 32 percent. The efforts of the trail managers to reduce group sizes may be responsible for some of the decline, but there is still a need to continue these efforts.

Most of the groups (45 percent) come from the camps and Scout troops of Vermont, Massachusetts, and Canada. Groups from other regions of the country account for about 30 percent. The higher proportion of local group use should enable the trail managing agency to keep the participating organizations well informed of new trail regulations and of preferred sites and dates for large group trips.

Figure 3.—A large organized group preparing to hike the Long Trail to Little Rock Pond.

Figure 4.—Tent platforms at Griffith Lake.

Membership in the Green Mountain Club

The majority of the overnight users of the Long Trail caretaker sites are not Green Mountain Club members. In 1976 only 14 percent of the total overnight visitors were GMC members, though at a few sites, close to 30 percent of the users were GMC members.

In the early 1900's, the Green Mountain Club had about 200 members. With increased interest in the club's conservation and recreation management work, membership grew steadily to about 3,700 persons by 1976.[4]

While the growth rate in club membership has averaged about 20 percent during the last 5 years, the proportion of GMC members using the Long Trail overnight sites has increased about 60 percent during this time. Most of these members are long-distance hikers, which may be an indication that younger people, the traditionally more active trail users, are joining the club.

Tenting and shelter preferences

A survey of southern Appalachian Trail users in Virginia, Tennessee, North Carolina, and Georgia indicated that hikers there preferred shelters to tents by a margin of three to one (Murray 1974). Appalachian Trail "through hikers" in the Shenandoah National Park preferred shelters to primitive camping and were more tolerant of large numbers of people at their overnight sites than the short-distance hikers.[5]

From caretaker records of overnight hikers on the southern section of the Long Trail (the Appalachian Trail section), it appears that equal proportions of hikers seem to prefer tenting and shelter camping. At six caretaker sites on the trail that offer a choice between tenting or shelter use (sites primarily at the southern ponds, Fig. 4), an average of 51 percent of the overnight visitors used tents each season since 1973. (This ranged from 35 to 70 percent, depending on the particular site and year.) At most of these sites, the caretakers live in

[4] Personal communication with Larry Van Meter, Exec. Dir., Green Mountain Club (1977).

[5] Preliminary study results from Ben W. Twight, W. Virginia University, Morgantown (1977).

Table 3.—Percentage of nights during the summer season (1975 and 1976) that tents were used, by shelter use level

Use	Shelter use level				Total for season
	Empty	1-50% full	51-100% full	Over-capacity	
Tents not used	6.6	20.6	7.8	1.8	35.9
Tents used	7.2	37.4	16.8	2.9	64.2

separate tents, so their presence should not affect the hiker's choice.

Table 3 shows the percentage of nights during the summer season that tents were used at different shelter occupancy levels. This table pertains to sites where there is a choice between using the shelter or using a tent. Tents were used most often when the shelters were less than half full or empty, and not just when the shelters were reaching crowded conditions (over half full). The desire for privacy may outweigh the convenience of shelter camping.

At Little Rock Pond, the shelters have been relocated out of view of the pond (up to 1/4 mile away) in an effort to reduce physical damage to portions of the shoreline. The opportunity to camp with a pond view is available only to tenters. It is therefore not surprising that 80 percent of the tenting at Little Rock Pond was done when the shelters were less than half full.

DISTRIBUTION OF HIKERS ON THE LONG TRAIL

Information from hiker registration sheets has been used to determine the relative distribution of hikers along the trail. From the sample of 20 and 21 sites for 1975 and 1976, respectively, the trail use by overnight hikers during the two seasons was plotted (Figs. 5 & 6). The geographic distribution of hikers on the trail was remarkably similar for both years.

Not all sections of the trail received the same amount of use. The most frequently used sections were those:

- Traversing the highest mountain peaks (over 4,000 feet) where short side trails (less than a 3-mile hike from a road) provide access to the Long Trail.
- Between a road and a scenic mountain pond less than 5 miles from the road.

The least-used sections were those:

- Traversing the lower mountain slopes in a fairly remote area north of the Appalachian Trail cut-off.
- Farthest from the northeastern metropolitan areas.

Overnight use was very high at two of the southern pond sites, Little Rock Pond and Stratton Pond, and at a site on Mt. Mansfield (Figs. 7 & 8). Lowest overnight use was at sites not shown with overnight facilities on the Long Trail Guidebook map and at sites located at the base of high mountains which also had overnight facilities at higher elevations.

Frequency of overnight site use

Daily caretaker records have been used to study the fluctuations in the use, or demand, for the overnight facilities. These figures provide two measures of site use: the percentage of the season that the site is used at different occupancy levels, and the regularity of the flow of visitors to the site. Together these measures can indicate what management attention, if any, might be needed at a given site.

The use patterns at each caretaker site differ according to the location and capacity of each site. Most of the shelters located near the summits of Vermont's two most popular mountains were over half full about 40 percent of the 1975 and 1976 seasons. In contrast to these, five of the caretaker sites were over half full less than 10 percent of the two seasons. Figure 10 shows the total seasonal visitor use of two different shelter sites—one with a fairly even distribution of use, and one with an uneven distribution. At Montclair Glen, a popular shelter site near the summit of Camel's Hump

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Figure 5.—Relative distribution of Long Trail use.

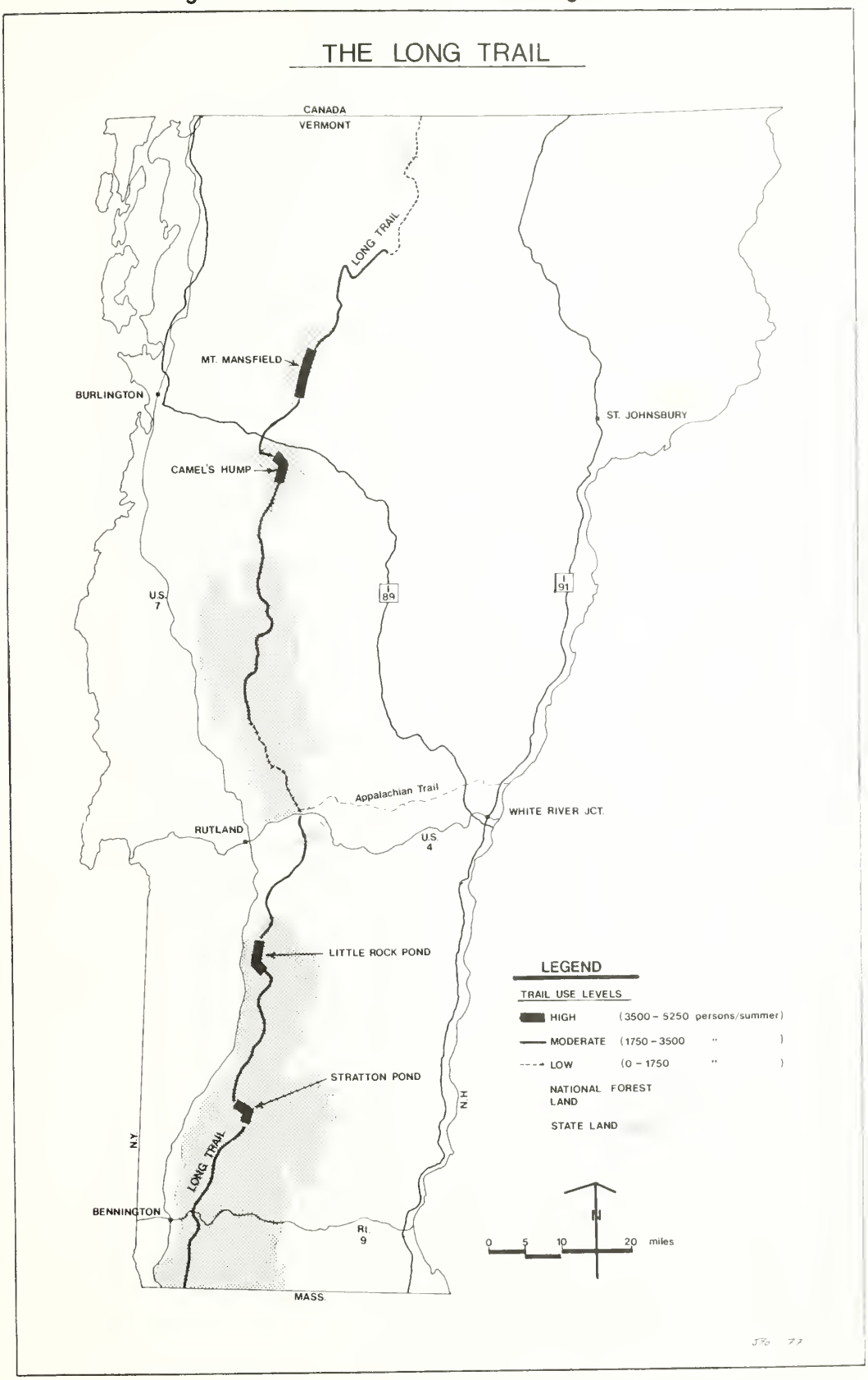
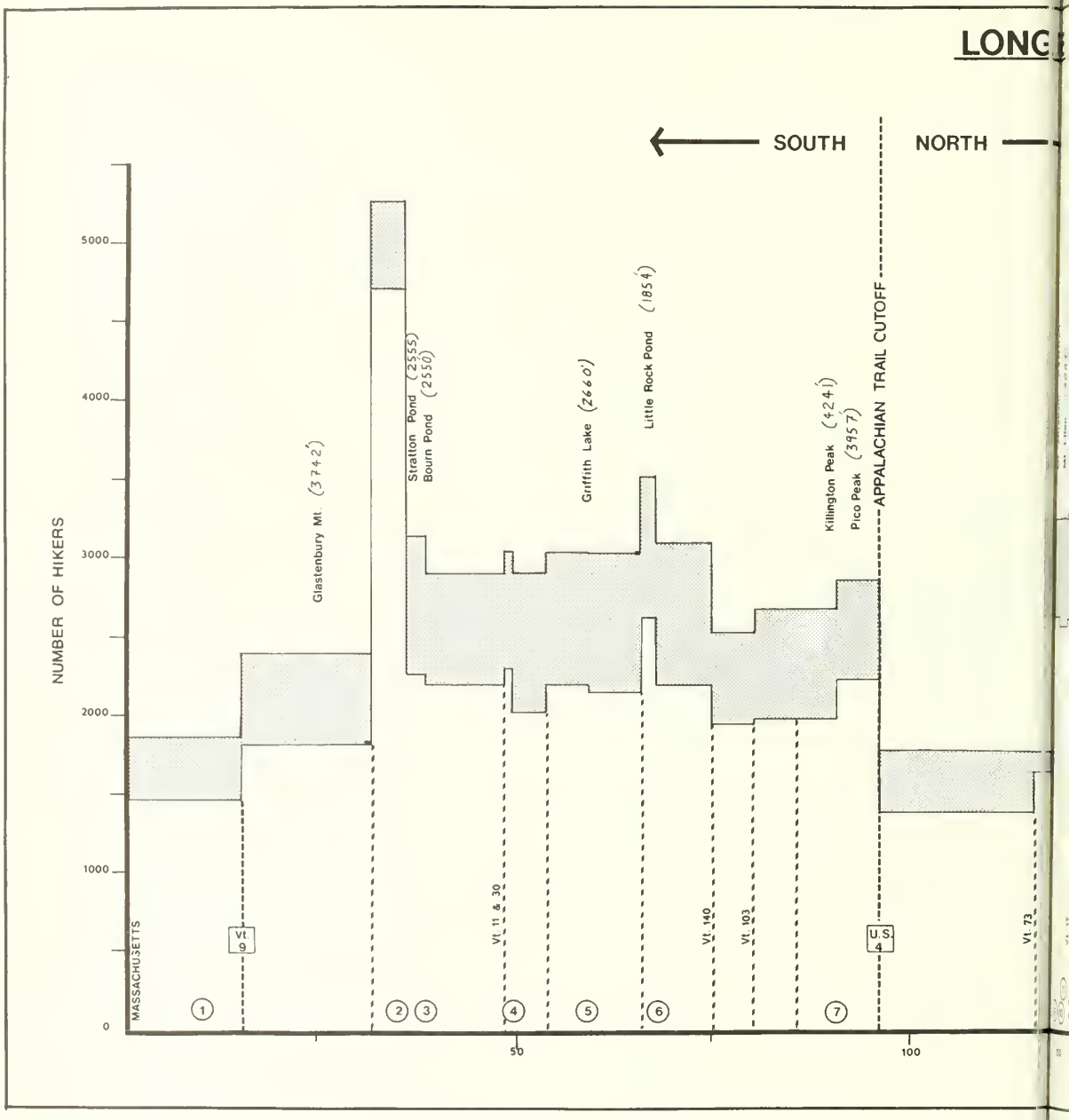


Figure 6.—Distributi



tors in 1975 and 1976.

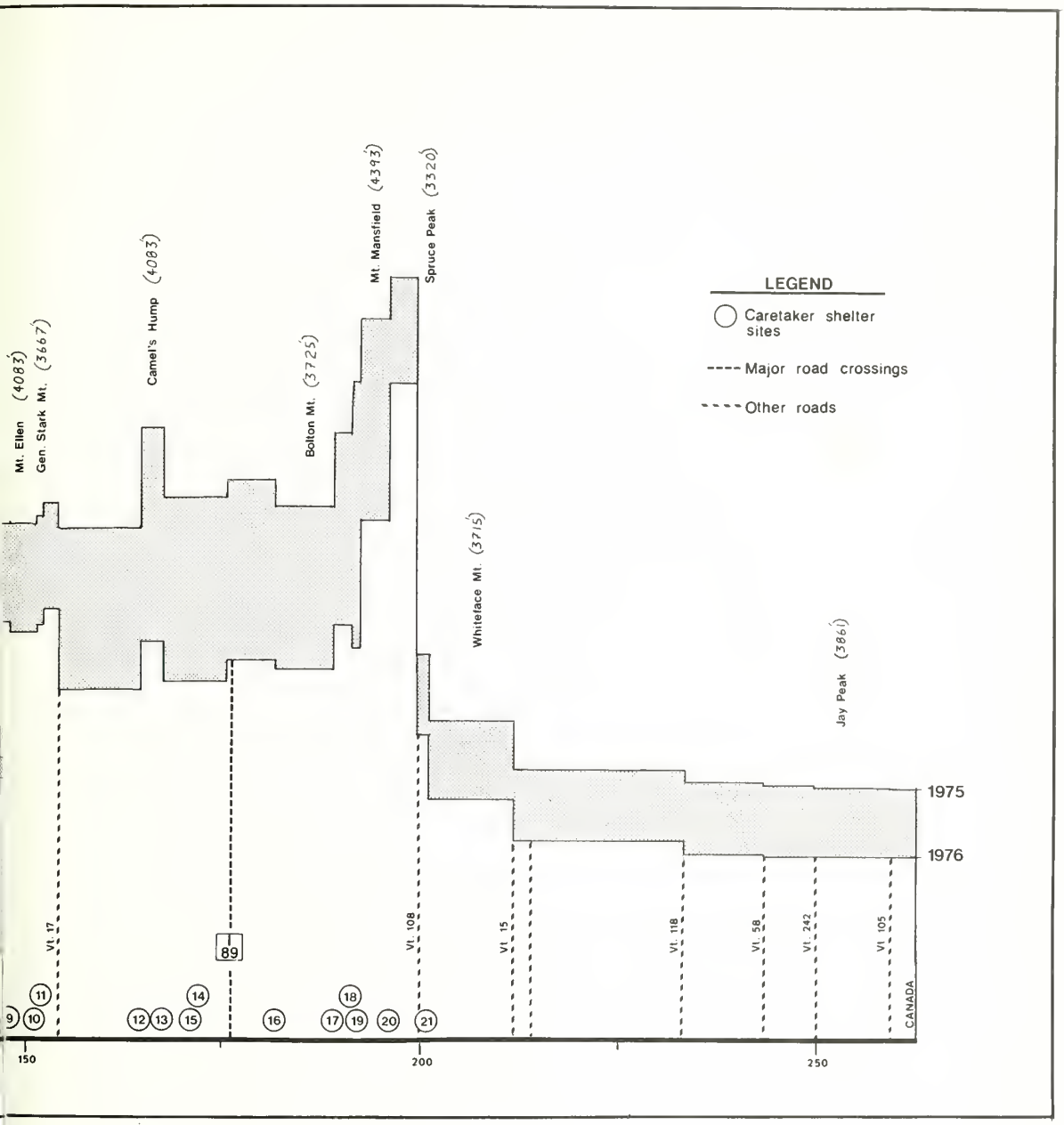


Figure 7.—View of Stratton Pond from one of the shelters.

(Fig. 9), visitor use exceeded the shelter capacity about 31 percent of the season (Fig. 10). The flow of visitors to this site was fairly even, however. The shelter was over half full about 50 percent of the season, and empty only 7 percent of the season. This shelter is on State land, so visitors may tent around the shelter only when the shelter is full. However, overflow conditions for a third of the season could indicate a need for additional facilities if use levels remain the same.

At Sterling Pond, a shelter site located near a less-popular mountain peak, the flow of visitors was very uneven. The shelter was empty about 30 percent of the season and over half full only 10 percent of the season (Fig. 10). The capacity of the site is over twice that of Montclair Glen and its occupancy was rarely overcapacity (1.3 percent of the season). This site could handle many more visitors than it does if managers attract more people to it.

Seasonal trends

During the summer season (May to September), overnight use of the more popular sites increases by a nightly average of six persons each month and peaks in mid-August. Several sites have been observed to attract fall weekend use that is as high or higher than summer weekend use. Caretakers might be advisable for some of the sites on fall weekends. Uncrowded trails, fewer insects, and the lightweight, warm camping gear now available may be factors that influence the hiking patterns of some backcountry recreationists in the Northeast.

Weekday/weekend comparisons

Visitor registration was used to determine whether weekend use of overnight sites was higher than weekday use. Five of the 21 caretaker sites remained empty over 40 percent of the weekdays

Figure 8a.—The Long Trail approaching Mt. Mansfield from the south.

Figure 8b.—Overnight site near Mt. Mansfield (Butler Lodge — elevation 3,040 feet).

(Sterling Pond, Buchanan, Stark's Nest, Castlerock, and Glen Ellen). Two of these sites were also empty over 40 percent of the weekend nights. Each of the five sites is located on or near a mountain of over 4,000 feet elevation, a generally attractive feature to Eastern backpackers.

The difference in numbers of visitors on weekend nights and on weekday nights was statistically significant for only about 25 percent of the caretaker sites (three to five more persons on weekend nights).[6] These sites were located near two popular high peaks and the southernmost pond site, Stratton Pond. In 1975, the four southern pond sites received heavier tenting use on weekends (4 to 15 more tenters per night on weekends). However, in 1976 only Stratton Pond received more tenting use on weekends.

In general, there is no great difference between weekday and weekend use at most of the caretaker sites. Only the three most popular locations on the Long Trail contributed to higher weekend use at the adjacent overnight sites.

[6] Determined at the 90 percent confidence level, using the analysis of variance statistical program of SPSS, Version 6 (1976).

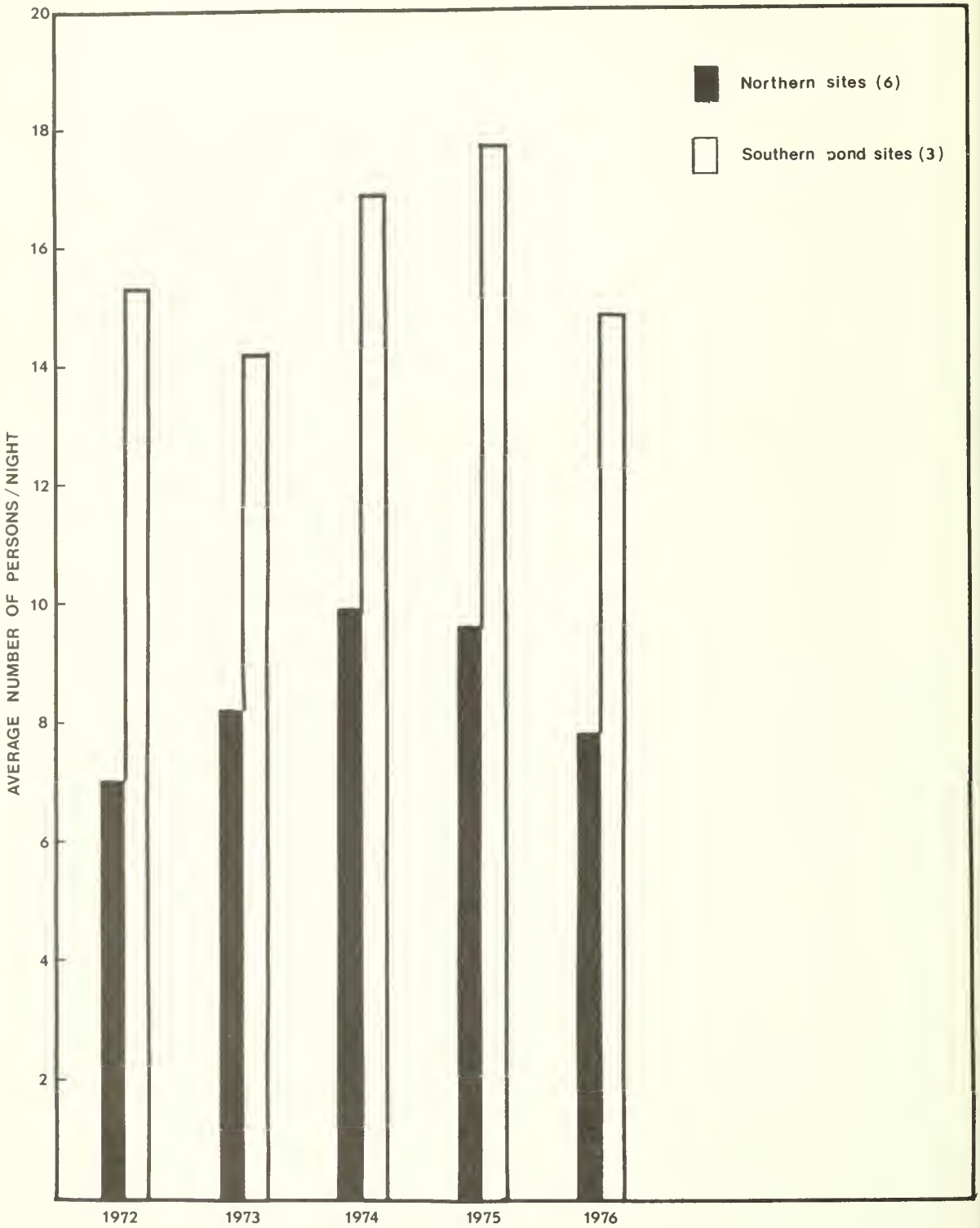
HIKER VOLUME

In 1976, the number of recorded overnight visitors during the summer season was between 60 and 2,000 persons per site, depending on the location, popularity, and capacity of the site. Use of the more popular overnight sites during the peak summer months, July and August, averaged about 8 persons per night at northern sites and 16 persons per night at southern sites.

Figure 9.—Montclair Glen (elevation 2,670 feet) — overnight site near Camel's Hump, Vermont.

the 1976 season.

Figure 11.—Average overnight use at caretaker sites (July and August).



Records of Long Trail use before 1970 are scarce. During the 1960's, trail managing groups observed significant increases in trail use by physical changes at shelter sites and the number of hikers encountered on the trail. Since 1972, when comparative records of overnight use were started, the average number of visitors per night per site increased until 1975, the peak year (Fig. 11). Sites at the popular northern peaks on State land have had relatively small fluctuations in use each year, despite the tenting regulations imposed since 1971. The southern pond sites have had greater fluctuations in use each year (average differences of 3 to 4 persons per night between years). In no case do the fluctuations show a clear downward or rising trend.

USE OF VISITOR RECORDS FOR MANAGEMENT DECISIONS

Trends in overall use levels are valuable for predicting future facility needs. Recreational preferences, however, are subject to erratic changes as economic or cultural conditions change. Probably the best that can be predicted from a few years of data is a pattern of use for the following 1 or 2 years.

Visitors' residence data can indicate where to direct educational information and regulations on trail use, and where funds to support backcountry facilities might be sought.

As most of the out-of-state visitors to the Long Trail come from Massachusetts, New York, and Connecticut, the trail-maintaining groups should direct their information to those states. A substantial portion of the short-distance hikers to the northern section of the trail are Canadians, therefore, Montreal and Quebec might also be targets for trail information.

As the trail is used most by out-of-state visitors, maintenance costs should not be left entirely to the State or local governments. State funding for the Long Trail, however, might best be used for the northern section of the trail since a large proportion of the hikers there are from Vermont.

The majority of the hiking parties travel in groups of one to three persons. The design of overnight facilities should take this into account. At sites where tent platforms are considered necessary to reduce ground compaction, platforms should be large enough to accommodate a two- or three-man tent, and most of the platforms should be spaced to give privacy to each party.

For large organized groups, platforms can be clustered together. A separate area should be chosen for these groups, preferably out of sight and sound of the other campers.

Most of the Long Trail shelters can accommodate, at most, only one large group at a time. At sites where it is deemed undesirable to have overcapacity conditions, some sort of reservation system for large groups may be necessary. This would reduce the possibility of having two groups at a site on the same day. Other hikers could also find out when to expect large groups at a specific site. Alternatively, separate tenting areas could be established primarily for large group use.

Green Mountain Club members account for less than 15 percent of the total visitor use at overnight sites, nevertheless the club should continue efforts to learn the preferences of the rest of the trail users. Their caretaker program can accomplish this by continued observation of visitor behavior and through informal discussions with the visitors.

Tenting is clearly preferred by some hikers. The availability of lightweight tents and stoves has made backpacking much more convenient than it was 15 years ago. In 1976, about 80 percent of the northern shelter visitors cooked their meals on portable stoves. Permanent shelters and sites with firewood are no longer essential, but are merely one type of amenity that should be included at some sites to provide a variety of backcountry opportunities.

The common assumption made by backcountry visitors and managers that there are hordes of weekend visitors using the shelter facilities is not entirely true. Visitor-use records can provide managers with more accurate information on available space, and decisions can be made to increase overnight capacities of those sites that are more frequently in demand or develop a system to limit the number of overnight visitors to these sites. Infrequent but heavy use of a fragile mountain site can be more detrimental to the physical durability of the site than evenly distributed use (Burden and Randerson 1971).

Trail managers can attempt to redistribute the use of a site over more of the season as well as encourage visitors to use other available sites. The means to accomplish this might include:

- Inform hikers about the relative use at each site

with the purpose of attracting hikers to the lesser-used sites.

- Charge a higher use fee at the heavily used sites.
- Charge higher fees on weekend nights at sites that receive heavy use on weekends.
- Alter the locations of shelters or side trails to the shelters.

Alternative management plans for a given site must take into consideration: (1) the management objectives for the entire trail-shelter system; (2) the use patterns at adjacent sites; (3) how much additional use a specific site can physically handle with available maintenance techniques and money; and (4) the social densities that will be most satisfactory to the overnight visitors. Once these questions are answered, the value of a backcountry-use inventory can be best realized.

CONCLUSION

Records of dispersed recreation site use have been viewed skeptically by managers as information too elusive and costly to obtain. But with a lack of meaningful data on visitor use, trail management decisions have verged on the arbitrary.

The actual use of trails and overnight shelters should be considered essential information when planning backcountry facilities. Site durability could then be compared to existing patterns of visitor use, and planners could arrive at logical solutions to potential problems.

Decisions to close or restrict the use of sites cannot be made without affecting some segment of the hiking population. The risk of causing dissatisfactions among large numbers of backcountry visitors by making an inappropriate decision may outweigh the cost of collecting data on visitor use. Likewise, the costs incurred by overdesigning some backcountry sites should encourage managers to learn to what extent the facilities are used. Judicious use of the limited budgets for the construction and maintenance of facilities requires that decisions be based on the actual use of the backcountry resources.

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LOGGING RESIDUE AVAILABLE FOR MINE-TIMBER PRODUCTION

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LOGGING RESIDUE AVAILABLE FOR MINE-TIMBER PRODUCTION

Abstract

Hardwood logging residue was examined as a source of raw material in the manufacture of sawn, split, and round timbers for use in underground coal mines. Forty-four percent of the total logging residue (residue $\geq$ 4 inches in diameter outside bark (dob), small end, and 4 feet long) from sawlog-only harvests was suitable for mine-timber production. Only 26 percent of the limbwood residue was suitable for mine timbers, but 58 percent of the bolewood residue was suitable. Depending on the species, the suitability for bolewood ranged from less than 40 percent (beech and basswood) to 68 percent (cucumbertree).

Figure 1.—Appalachian bituminous coal region [the entire shaded area] (U.S. Department of Interior 1966) and predominant forest cover types of that region (Little 1971).

INTRODUCTION

THE EASTERN HARDWOOD FOREST encompasses the Appalachian bituminous coal region (Fig. 1). In 1965, more than 60 percent of the total coal production in the United States and nearly 78 percent (231 million tons) of the total U.S. production of coal from underground mines came from this large deposit (West Virginia Coal Association 1976). And the eastern hardwood forest accounted for the estimated 300 million board feet (1.3 board feet per ton) of sawn timber and 125 million lineal feet (0.54 lineal foot per ton) of round and split timber used in mining this coal.[1]

There are three principal sources of raw material used in the production of mine timbers: low-quality portions of grade logs; low-grade material harvested specifically for mine-timber manufacturing; and good-quality (but often pole-size) trees harvested specifically for mine timbers.

There is also a fourth possible source: residue from sawlog harvesting. An estimated 80 million cubic feet of residue is produced each year in West Virginia alone (Martin 1975), much of it located near mine-timber markets. After observing that logging residues contain raw material that is suitable for mine-timber production, I determined the proportion of total residue volume that could be used for this purpose.

THE STUDY

Residue was measured on 21 randomly selected areas within the Appalachian bituminous coal region. These sample areas had been cut for sawlogs only, and were located between the Virginia-Tennessee border and north-central West Virginia. Sampling was stratified by three cover types: oak-hickory, northern hardwoods, and cove hardwoods.

Four 1/4-acre circular plots were established in each sample area. The first plot was established randomly by the field crew; each of the remaining plots was established in random direction at a 4-chain interval.

Within each plot, pieces of residue that met the following standards were measured:

- Equal to or greater than 4 feet long
- Equal to or greater than 4 inches in diameter outside bark (dob) at small end
- Lie within plot boundary or pieces that crossed one-half the plot boundary (pieces crossing the remainder of the boundary were ignored).

For each piece of residue, the following was recorded:

- Species
- Position in the tree
  - (a) bolewood: main stem to a 4-inch top, or to where the stem breaks up
  - (b) limbwood: to 4-inch small diameter
- Large and small end dob (to nearest 1/2 inch)
- Length (to nearest 1/2 foot)
- End diameters and lengths for each portion of the piece suitable for one of the following classes:
  - (a) standard sawn mine timbers: 6 to 16 feet long, 7-inch minimum diameter inside bark (dib)
  - (b) specialty sawn mine timbers: 30 inches long or multiples thereof, 6-inch minimum dib, or 18 inches long or multiples thereof, 12-inch minimum dib
  - (c) mine props: 4-1/2-inch minimum dib; 4-1/2-foot minimum length; 1-inch increase in dib for each 1-foot increase in length.

The material was classified only once in the order given above. However, much of the material in the first class could be used in either of the other classes. The piece size and general characteristics that determine mine-timber classification were developed after inspecting both raw materials and mine-timber products, and from producer's comments on specifications. From this information we developed a set of minimum standards for mine-timber raw material.

After the measurements were obtained, the total cubic-foot volume of each piece was calculated, using Smalian's formula. This information was then summarized and broken down by species into the following classes:

- Suitable for general sawn products (6 to 16 feet long)
  - (a) total
  - (b) $\leq$ 10-inch, small dib
  - (c) $>$ 10-inch, small dib
- Suitable for props
  - (a) total
  - (b) 4.5 through 5.5 feet long
  - (c) $>$ 5.5 feet long

[1] Knutson, Robert G. 1970. Wood use in mines. Unpublished report on file at Forestry Sciences Laboratory, Princeton, W. Va. 35 p.

- Suitable for specialty sawn products
  (a) Total
  (b) < 30 inches long (≥12-inch dib, small end)
  (c) ≥30 inches long (≥6-inch dib, small end)

The preceding breakdown was repeated for each of the three residue categories: all residue, bolewood, and limbwood. All volumes were then converted to percentages.

RESULTS

An analysis of variance showed no differences among the three cover types; therefore, this stratification was discarded. The percentage of usable residue for each class is shown in Tables 1 through 3. Of all residue material remaining after a saw-log-only operation, 44 percent was physically suitable for use in manufacturing mine timbers.

Limbwood accounted for 42 percent of the total residue (Table 4); of this limbwood, only 26 percent could be classified as usable. Bolewood accounted for 58 percent of the total residue (Table 4); of this bolewood, 56 percent could be used for some form of mine timber.

Because only 26 percent of the limbwood would be suitable for the manufacture of mine timbers, a large volume of material would have to be handled for a relatively low-volume return. Therefore, because of the anticipated harvesting problems and relatively low value of material being harvested, it does not seem feasible to consider harvesting limbwood at this time. The remainder of this paper will be concerned with bolewood only.

For all bolewood measured, over one-half was more than 20 feet long and over one-third was more than 10 inches in diameter at the small end. Forty-eight percent of the bolewood residue was in material 7 inches or more in diameter and 6 to 16 feet long; this material is suitable for production of sawn timbers on a standard mine mill (Table 3). The remainder of the usable bolewood residue was suitable for props or for use in specialty mills producing wedges or crib blocking.

In determining the suitability of residue for mine-timber production, the choice of species is important. The choice depends on where the product is to be used, past experience of mine

Table 1.—Percentage of hardwood logging residue usable for the manufacture of mine timbers

ALL RESIDUE

Species	Sawn mine timbers (Standard mill)		Sawn mine timbers (Specialty mill)		Mine props		Total usable residue
	≤10″ diameter	>10″ diameter	18-30″ long	≥30″ long	4.5-5.5′ long	>5.5′ long	
Chestnut oak	16	20	0	6	1	1	44
Red Oak	20	13	0	8	3	0	44
White oak	17	16	0	5	4	1	43
Hickory	22	10	0	8	3	2	46
Basswood	16	3	0	4	0	2	25
Cucumbertree	26	20	0	2	2	0	50
Yellow-poplar	35	8	0	6	2	1	52
Beech	7	24	0	3	1	1	36
Red maple	18	17	0	7	3	0	45
Sugar maple	20	6	0	7	3	0	37
Birch	28	10	0	7	1	0	46
Black cherry	11	6	0	16	1	0	34
Miscellaneous	14	24	0	5	5	1	49
All species	20	14	0	6	3	1	44

Table 2.—Percentage of hardwood logging residue usable for the manufacture of mine timbers

LIMBWOOD

Species	Sawn mine timbers (Standard mill)		Sawn mine timbers (Specialty mill)		Mine props		Total usable limbwood residue
	≤10″ diameter	>10″ diameter	18-30″ long	≥ 30″ long	4.5-5.5′ long	>5.5′ long	
Chestnut oak	6	0	0	6	1	0	13
Red Oak	12	5	0	9	4	0	30
White oak	7	5	0	6	6	0	24
Hickory	13	3	0	9	4	1	29
Basswood	0	0	0	4	2	0	6
Cucumbertree	16	0	0	1	3	0	20
Yellow-poplar	11	0	0	8	4	0	23
Beech	12	8	0	6	3	0	29
Red maple	9	4	0	8	4	0	25
Sugar maple	9	2	0	6	5	0	22
Birch	7	10	0	13	1	0	31
Black cherry	10	0	0	12	1	0	23
Miscellaneous	13	0	0	3	6	0	22
All species	10	4	0	8	4	0	26

Table 3.—Percentage of hardwood logging residue usable for the manufacture of mine timbers

BOLEWOOD

Species	Sawn mine timbers (Standard mill)		Sawn mine timbers (Specialty mill)		Mine props		Total usable bolewood residue
	≤10″ diameter	>10″ diameter	18-30″ long	≥30″ long	4.5-5.5′ long	>5.5′ long	
Chestnut oak	24	35	0	1	0	7	67
Red Oak	32	23	0	6	2	0	63
White oak	25	27	0	5	1	0	60
Hickory	31	18	0	8	2	3	62
Basswood	22	5	0	3	2	0	32
Cucumbertree	32	31	0	3	2	0	68
Yellow-poplar	41	10	0	5	2	1	59
Beech	5	32	0	1	0	1	39
Red maple	24	24	0	6	2	0	56
Sugar maple	29	11	0	8	2	0	50
Birch	37	10	0	4	1	0	52
Black cherry	12	15	0	20	0	0	47
Miscellaneous	15	35	0	16	5	1	62
All species	26	22	0	5	2	1	56

Table 4.—Percentage of bolewood and limbwood in Appalachian logging residue

Species	Bolewood	Limbwood
Chestnut oak	57	43
Red oak	45	59
White oak	52	48
Hickory	51	49
Basswood	71	29
Cucumbertree	65	35
Yellow-poplar	79	21
Beech	64	36
Red maple	63	37
Sugar maple	54	46
Birch	68	32
Black cherry	42	58
Other	68	32
All species	58	42

operation in the use of different speeies, and what is available. In general, hard hardwoods (oaks and hickories), because of their durability and strength, are preferred over soft hardwoods (basswood and yellow-poplar) or softwoods (hemlock and pine). Some mines accept only the preferred species no matter where the wood is to be used. Some mines accept the less preferred species for use in noncritical areas.

Of the species actually used in mines for all purposes (sawn and round), an estimated 55 percent of the sawn timber volume is oak—primarily red oak; 15 percent hickory; 15 percent yellow-poplar, basswood, and cucumbertree; 6 percent beech; 5 percent pine and hemlock; and 4 percent miscellaneous hardwoods. Round and split timber consists primarily of oak, hickory, and beech (Knutson 1970).

Oak-hickory is the most common major forest type in the northern part of the bituminous coal region (Fig. 1). In the coalfield areas (areas of Kentucky, Tennessee, and Alabama), the predominant forest type is oak-hickory and oak-pine. Because of the extent of these forest types, there should be a relatively high portion of residue in the preferred species category.

In considering percent yield of usable residue for individual species (Table 3), the cucumbertree has a slight edge. Sixty-eight percent of the bolewood is usable for manufacturing some form of mine timbers. The cucumbertree, however, usually is used only for such items as wedges, or in noncritical areas, if used at all. Of the preferred species, the oaks and hickories, 60 percent or more of the bolewood residue is in material suitable for mine-timber production. Yellow-poplar, another species used primarily for wedges or in noncritical areas, has almost 60 percent usable bolewood residue. Beech and basswood yield less than 40 percent usable material from residue. However, both species are low on the preference scale.

DISCUSSION

Much of the wood used in soft coal mining could come from salvaging hardwood sawlog residue (Figs. 2A, 2B, 2C). The best opportunity would be to use bolewood residue, since bolewood accounts for most of the usable volume, and would be more economical to harvest.

In West Virginia, for example, and estimated 88,500,000 tons of coal were produced from underground mines in 1975 (West Virginia Coal Association 1976). This required 23,000,000 cubic feet of sawn timbers and 11,179,000 cubic feet of round or split timbers. The 80,000,000 cubic feet of total residue generated each year would yield enough usable bolewood to supply raw material for all the sawn timbers and one-third of the props (based on an average prop of 53 inches in length, a top diameter of 6 inches, and a conversion factor of 5 board feet of sawn product per cubic foot).

FURTHER RESEARCH

Although we estimate that 44 percent of the residue from sawlog cutting is suitable for mine-timber production, very little is considered economically suitable. There should be research on harvesting methods that might yield an adequate return on investment from residue extraction. Also needed are new methods that will minimize damage to the residual stand during residue harvesting operations.

Figure 2A.—"Residue" from a hardwood sawlog cutting operation.

Figure 2B.—A typical Appalachian mine-timber production mill.

Figure 2C.—Storage yard for coal-mine timbers.

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ABSTRACT

Logging accidents are costly. They may bring pain to injured workers, hardship to their families, and higher insurance premiums and lower productivity to their employers. Our analysis of 1,172 injuries in central Appalachia reveals that nearly half of all time lost—and almost all fatalities—resulted from accidents during felling and unloading. The largest proportion of serious injuries, fatalities, and costs were among young or new workers and during the late spring and early summer, when logging is at its peak. Safety programs should concentrate on these high-hazard areas. Statistical summaries are provided to aid in the development of such programs.

HAZARDS AND HIGH COSTS

LOGGING is one of the most hazardous of all American industries. In 1974, about 28 out of every 100 loggers suffered job-related injuries. Over half of these injuries resulted in lost workdays, and some of them in death.

Among 240 industries reported on by the Bureau of Labor Statistics, logging ranked first in incidence and second in severity of injuries causing lost workdays. The incidence—15.6 per 100 full-time workers—was 3 1/2 times greater than that for manufacturing, and far over other industries in the lumber and wood products group. Only water transportation had a higher number of workdays lost per full-time worker (U.S. Department of Labor 1976).

There are several reasons why logging has higher injury rates than other industries. The work is often strenuous, and is done out-of-doors where there is no control over weather and terrain. Work sites change frequently and present new hazards to which workers must adjust. The work force is scattered over a wide area. And, certain characteristics of the industry are conducive to high injury rates—seasonal work, high employee turnover, and piece-rate payment which may encourage haste and carelessness.

A measure of the economic burden of work injuries is the cost of workmen's compensation insurance. During 1976, manual or base rates for workmen's compensation on logging operations in the eastern United States ranged from a low of $12 per $100 of payroll in Alabama to a high of $50.48 in Kentucky. Nearly one-third of the states had rates of more than $25 per $100 of payroll.

Still, workmen's compensation represents only about one-fourth to one-half of the total cost of work injuries. Uninsured costs that must be borne by private employers include wages paid to both the injured man and other workers who stop work to give assistance, damage to materials and equipment, lost production, and the cost of recruiting and training replacements. High injury rates also create a poor image of the logging industry, which makes it more difficult for employers to recruit labor and borrow capital.

In light of the high cost of work injuries, it is important that the logging industry make a special effort to reduce these injuries by emphasizing safety practices and regulations. Injury statistics can be a valuable tool for the industry because they reflect the past experience of many companies and individuals. Statistical summaries of large numbers of accidents can provide clues about the kinds of hazards to be controlled, and situations to be avoided, and suggest the safety measures to be taken to reduce costs and prevent human suffering. Such summaries are especially valuable for developing and monitoring accident prevention programs.

THE STUDY

This study was made to provide information on when, where, and how workers are injured in Appalachian logging operations. It provides statistical summaries needed to set priorities in safety programs and it recommends general guidelines for avoiding logging accidents.

The investigation was limited to logging operations in West Virginia, Kentucky, Tennessee, and Virginia that produced pulpwood, saw logs, mine props, and various other roundwood products. All timber harvesting activities from the stump to the point of delivery are represented.

The study was based on loggers' reports of injuries in the above states during 1971 and 1974. The "Employer's First Report of Injury"—a one-page form—must be submitted to state workmen's compensation agencies. The reports varied slightly by state, but always gave a description of the injury and some general information about the injured worker. Data from such reports have been found to identify the characteristics of injuries correctly over 90 percent of the time, and thus are sufficiently accurate for general research and analysis (Mazor 1976).

The reports covered 1,172 injuries. The data were analyzed by chi-square tests of independence which indicated no significant differences in key variables—sources of injury, type of accident,

part of body injured, and nature of injury—between injuries reported in 1971 and in 1974. However, in 1974 a slightly higher proportion of workers were injured while limbing and a lower proportion while bucking and loading.

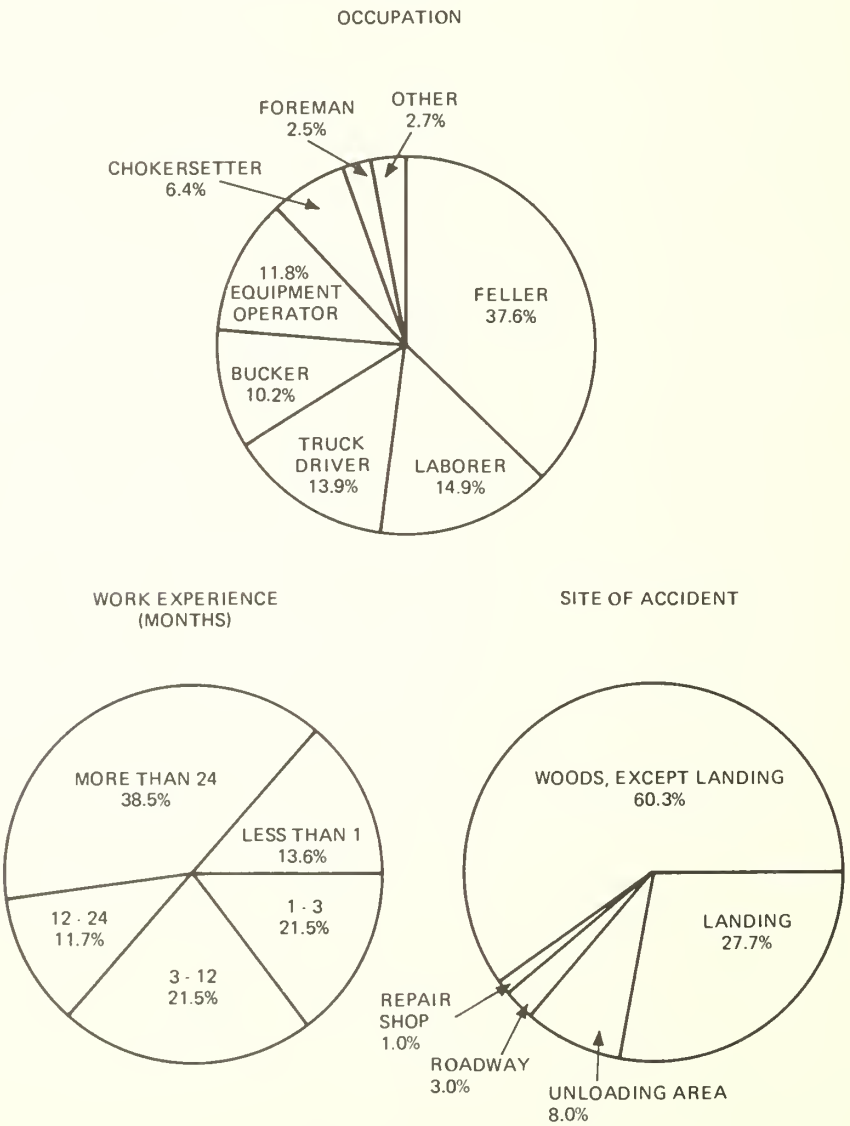
Injuries ranged in severity from relatively minor cuts and bruises to fatalities. All injuries required either some form of medical treatment or restricted the job assignment of the worker. The sample included 18 fatalities, 713 disabling or time-lost injuries, 212 nondisabling injuries, and 229 cases where the severity of the injury was not reported.

THE INJURED: WHO, WHEN, WHERE

Many of the injuries reported by loggers in Appalachia were related to youth and inexperience. In the sample, 36 percent of those who were injured were under the age of 30; however, nationwide, this age group represents only 29.9 percent of the logging labor force (U.S. Dep. Commer. 1973). The median age of those injured was 35, which is 3 years below the median for all loggers.

Many of the injured had been employed only a short time before their accident (Fig. 1). One-half

Figure 1.—Work injuries in logging by occupation, work experience, and site of accident.



had less than a year's work experience with their employer and one-third had less than 4 months. Nearly 14 percent had been on the job less than a month—which suggests that employers need to provide more intensive safety training to new employees.

Two-thirds of those injured were fellers, truckdrivers, and general laborers. A greater number of workers are exposed to the hazards of felling work, and fellers suffered more injuries than any other logging group. Again, newly-hired workers had proportionately more injuries while setting chokers and limbing trees. They were more likely to be struck by falling trees and caught under or between logs than experienced workers.

The number of injuries varied by season of the year, day of the week, and time of day. Injuries were most common during June, July, and August when logging is at its peak. Employers will find it profitable to emphasize safety training during this period when many new workers are hired and regular employees return after winter layoffs.

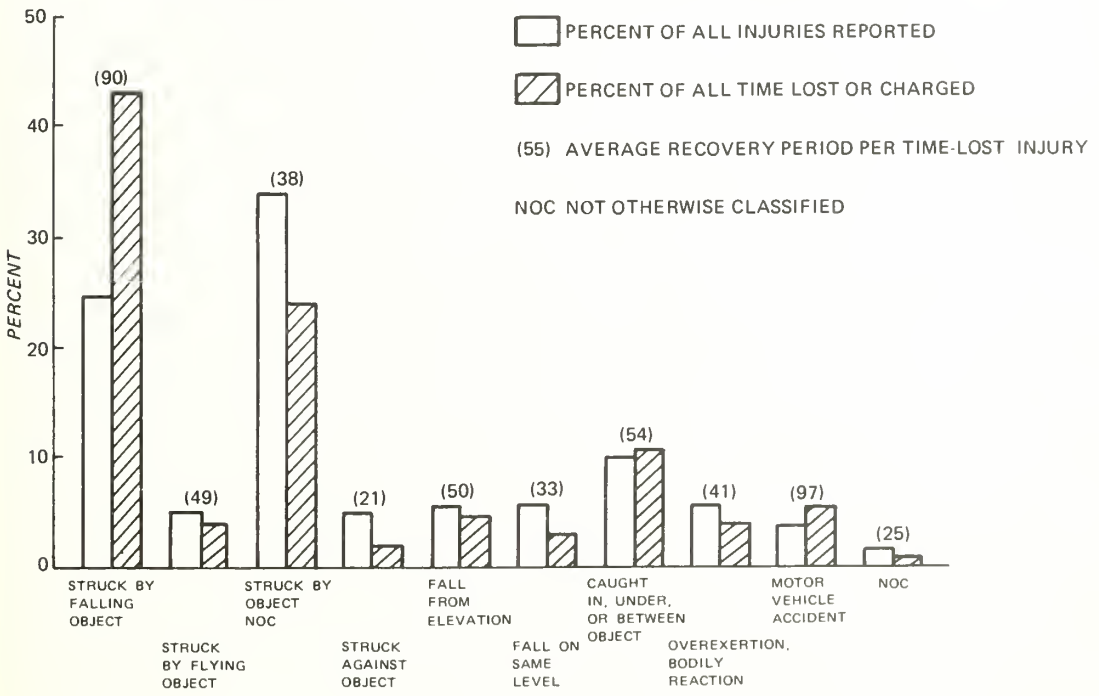
Accidents that caused injuries occurred more often during the first part of the week and reached a peak on Wednesdays. Only about 4 percent of all injuries were incurred on weekends. The peak hours when injuries were incurred were between 10 and 11 o'clock in the morning and 2 and 3 o'clock in the afternoon. The number of injuries sustained on Monday mornings and Friday afternoons was not unusually high or low.

Accidents in wooded areas other than landings accounted for 60 percent of all injuries. Twenty-seven percent of the injuries were incurred at landings, while the remainder were incurred along roadways, in repair shops, and at unloading points.

INJURY PATTERNS

To obtain more specific information about logging injuries, we classified each injury by (1) what the worker was doing when injured; (2) the nature of his injury (i.e., laceration, fracture); (3) the part of his body that was injured; (4) the object or substance that inflicted the injury; and (5) how the accident took place (i.e., fall from an elevation, struck by a flying object). These analytical categories were crosstabulated by the number of nonfatal injuries reported and the number of days lost. Time lost for permanent impairments such as amputations and loss of sight is

Figure 2.—Percentage of nonfatal logging injuries by accident type, Central Appalachian area, 1971 and 1974



charged at a standard rate recommended by the American National Standards Institute (1974). For all other injuries, time lost is the actual number of consecutive calendar days that the injured person is unable to work. The day of the injury and the day the worker returns to his job are not counted.

Type of accident

The most serious accidents occurred when loggers were struck by falling objects. Falling trees, limbs, logs, and various other objects accounted for 24.7 percent of all injuries and 42.7 percent of all time lost (Fig. 2). Workers disabled by accidents of this type required an average of 90 days to recover from their injuries. This compares to an average recovery period of 55 days for all time-lost injuries. Even more important, this type of accident resulted in 17 of the 18 logging fatalities.

In contrast, there were relatively few cases of workers injured by flying objects. Of those reported, about half involved flying wood chips, sawdust, bark, and other small particles.

The remaining cases where a worker was struck by an object comprised one-third of all logging injuries and one-fourth of all time lost. Most of these accidents were caused by kickbacks from power saws (57 percent), rolling logs (9.3 percent), and the whipping movement of branches and saplings (16.7 percent).

Falls accounted for slightly more than one-tenth of the total injuries. Half of these were from an elevation, while the others were on the same level. Workers who fell from elevated surfaces were usually loading trucks (41.4 percent) or getting on or off skidders, loaders, and other equipment (22.4 percent). Some of those accidents could have been avoided if the workers had been more cautious when dismounting from their equipment, and if exitways had been better designed.

Falls on the same level usually happened when loggers stepped in holes; tripped over branches, logs, and stumps; or slipped on leaves, bark, and loose rocks. Many of these accidents were uncontrollable because of the nature of the work locations. However, several falls occurred as fellers were running to get away from falling trees. If better escape routes had been planned, some of those accidents could have been avoided.

Workers were frequently caught in, under, or between objects—usually logs, equipment, chains, and cables—which caused nonimpact injuries such as pinched or crushed hands, fingers, feet, or other body parts. These accidents commonly occured when workers were loading and unloading trucks, setting chokers, or bucking logs.

There were 41 motor vehicle accidents—31 truckdrivers and 10 operators of skidders, dozers, or other vehicles were injured. In addition to the often serious injuries to the drivers, many of these accidents resulted in substantial property damage.

Other types of accidents that were not recorded separately included those related to temperature extremes (burns, heat exhaustion, frostbite); electric current; poison ivy; and bites or stings from snakes and bees.

Source of injury

Chain saws were the direct source of the greatest number of injuries (24.2 percent), followed by logs (20.9 percent), and limbs and saplings (16 percent).

Accidents caused by chain saws occurred in various ways, although, most resulted from saw kickbacks:

Saw kicked back	156
Saw thrown or pushed against worker	30
Worker fell while using or carrying saw	26
Worker struck hand or other part of body against saw	11
Chain broke or slipped off saw	4
Worker injured while starting saw	3
Worker injured while repairing saw	2
Not known	38
Total cases	270

The percentage of workers injured by chain saws while limbing was 50.6 percent; while bucking, 27.7 percent; and while felling, 9.5 percent. Most injuries were on the legs and ankles (47.8 percent), arms and wrists (14.3 percent), hands (10.7 percent), and fingers (11 percent). Although chain saws caused nearly a fourth of all injuries, they accounted for only 11.6 percent of the time lost—workers required an average recovery period of 24 days. This indicates that most of these injuries were less serious than those caused by falling objects.

Log-related accidents accounted for 1 out of every 3 lost days. The most serious of these accidents were caused when logs fell on workers who were loading and unloading trucks. Accidents occurred in the following ways:

Struck by falling log	70
Struck by rolling log	35
Struck against log	3
Fall from elevation onto log	6
Fall from same level onto log	9
Caught in, under, or between log(s)	74
Overexertion from lifting, pushing, or pulling logs	36
Total cases	233

Injuries inflicted by limbs and saplings accounted for one-fifth of the time lost. Accidents most often happened when dead and broken limbs fell from standing timber and when branches broke away from cut trees as they fell to the ground. During limbing and bucking, other injuries were caused when branches and saplings under tension were released and sprung back, striking workers.

Part of body injured

Legs, ankles, feet, and toes were the most likely to be injured in logging accidents. The lower body extremities incurred 38.5 percent of all injuries. The upper extremities—arms, wrists, hands, and fingers—received 21.2 percent of all injuries. The remaining injuries were to the trunk (20.2 percent); the head, face, and neck (14.1 percent); and more than one major body part (6 percent).

Legs and ankles were especially vulnerable, and were injured in 29.2 percent of the cases. These injuries represented 41.5 percent of the time lost—far more than from injuries to any other part of the body. The most common leg and ankle injuries were cuts and lacerations (49.1 percent), fractures (19.6 percent), and bruises (18.6 percent). More than four out of every five cuts and lacerations were caused by chain saws; fractures and bruises were most often caused by rolling or falling logs.

Back injuries can be especially troublesome. In almost 9 percent of the accidents, workers suffered back injuries—the majority of which were strains and sprains. Most of these injuries were caused when workers loaded trucks by hand. In the future, the number of back injuries should be reduced by the increased use of mechanical loading equipment.

Eye injuries are also important to guard against since they can easily result in impairment or loss of sight. Of the 42 cases reported, two resulted in partial or complete blindness. Branches or small saplings, whipping across the face, and flying particles of sawdust, bark, and dust were the major causes of eye injuries.

Nature of injury

Cuts, lacerations, and punctures were the most common nonfatal injuries (37.5 percent); followed by bruises, contusions, and concussions (21.6 percent). Two-thirds of the cuts, lacerations, and punctures were caused by chain saws; about half of the injuries were on the legs and ankles. Branches and small saplings caused the next greatest number of cuts and lacerations, many of which were on the head, face, and hands.

Fractures and amputations were the most serious nonfatal logging injuries. Although less than 1 percent of all injuries resulted in amputations, they accounted for nearly a fifth of the total time lost charged to work injuries. Of the six cases reported, two workers had their legs crushed when logs rolled off trucks that they were unloading. The other four lost fingers either in chain saw accidents or during the loading of logs and equipment.

Fractures comprised 16.1 percent of all injuries but accounted for slightly more than one-third of the time lost because of work injuries. Workers who suffered fractured bones were away from their jobs an average of 15 weeks. Bones were fractured most often when loggers were struck by falling or rolling logs, trees, and branches. The 159 fractures that were reported were distributed as follows:

Leg, ankle	57
Foot, toe	30
Hand, finger	16
Trunk, except back	16
Head, face, neck	14
Arm, wrist	10
Back	8
Multiple parts	8
Total cases	159

ACTIVITY WHEN INJURED

The five logging activities that accounted for the most injuries were limbing (18 percent), felling (17.5 percent), loading trucks (14.6 percent), bucking (11.9 percent), and setting chokers (7.3 percent). When these activities were ranked by the proportion of time lost, unloading trucks was first, with 24.7 percent, followed by felling (21.1 percent), limbing (11.2 percent), loading (10.6 percent), and bucking (10.1 percent). Felling and unloading were the two most dangerous logging activities (Fig. 3). Injuries to workers engaged in these activities accounted for almost half of the time lost and more than three-fourths of the fatalities.

Felling to bucking

The greatest hazard in felling timber is being struck by falling trees and limbs. Accidents of this type were responsible for over 70 percent of all felling injuries and 5 of the 18 fatalities. While information about these accidents is limited, there were several patterns of events that were common among them. In 14 cases, the tree that was being felled kicked back off the stump, striking the cutter. Several more accidents occurred when a falling tree hit standing trees that changed the direction of the fall, and the tree struck the cutter. In some cases, a chain reaction started when a falling tree hit a second tree or dead snag that fell, striking the cutter. Other accidents happened when the feller attempted to cut a tree in which a second tree was lodged.

Several serious felling accidents were described in the accident reports:

- Feller cut a tree with a grapevine in it that broke off a limb in a second tree. The limb fell and struck the feller in the back of the head, which resulted in his death.
- Feller cut a tree that knocked over a snag as it fell. The snag struck the worker and killed him.
- A falling tree hit a second tree that changed the direction of its fall. It grazed the feller's hip, knocked him down, and fractured his leg. The feller was off work for 31 weeks.
- A cut tree struck the ground, bounced back toward the stump, and hit the feller. The feller was unable to return to work for 13 weeks because of a dislocated hip.
- A broken limb dropped from a tree that was being cut, and fractured the feller's collarbone. The feller recovered from the injury and re-

Figure 3.—Percentage of nonfatal logging injuries by activity of worker, Central Appalachian area, 1971 and 1974

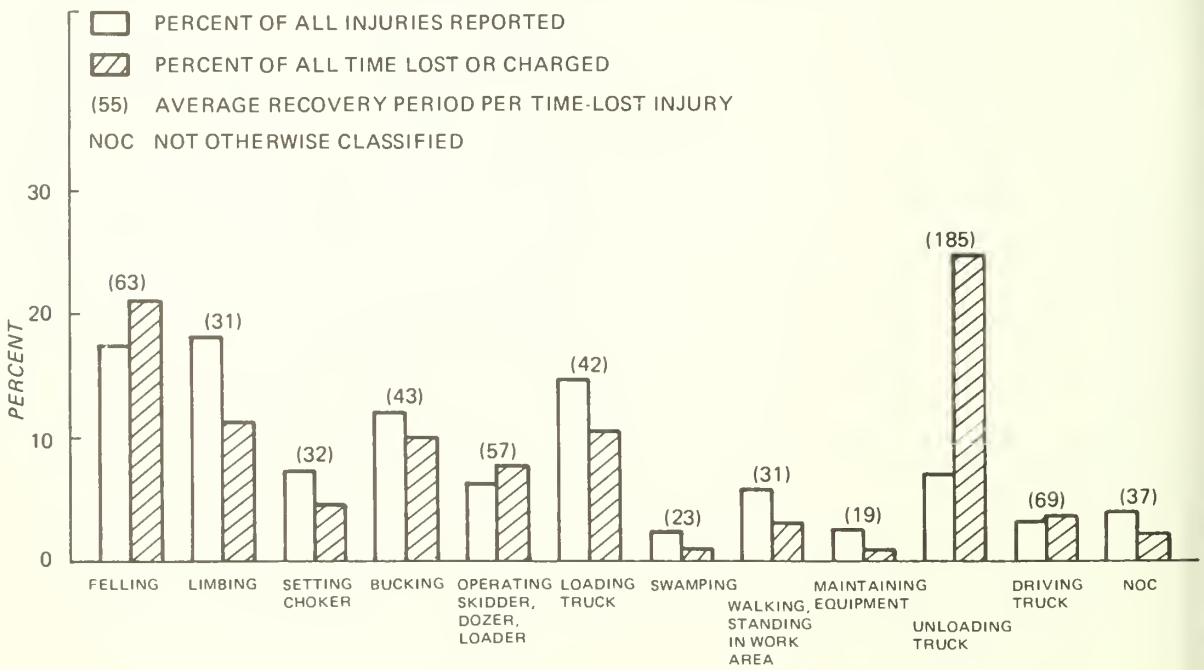


Figure 4.—Loading large saw logs is a hazardous activity requiring good footing, balance, and communication.

turned to work after being off the job for 11 weeks.

More injuries were the result of limbing and topping operations than of other timber harvesting activities. However, the injuries were generally less serious than those incurred from other major activities. About 1 month was lost per time-lost injury, which is far less than the average for all logging injuries. Two-thirds of the injuries were caused by chain saws. Injuries were also commonly caused when branches and saplings were cut, then sprang upward and struck the worker. Nearly half of all injuries incurred while limbing and topping were on the legs and ankles.

Several different types of accidents befell choker setters. Some of the more common ones were:

- Workers were struck by rolling logs when hooking and unhooking chokers. There were also several cases where workers were struck by rolling stones that had been dislodged by skidders.
- Workers were struck by saplings and dead trees that were knocked down by skidders or the logs they were pulling.
- Workers jammed wire into their hands while pulling frayed cables.
- Workers fell or tripped because of poor footing.

Some of the less common accidents resulted in the more serious injuries. For example, in two cases, chokersetters were walking alongside skidders when they slipped and were run over. In a few other cases, workers were seriously injured when broken limbs fell on them while they were setting chokers.

Injuries received while bucking were similar to those received while limbing and topping. Slightly more than half the injuries were inflicted by chain saws, usually on the legs and ankles. Injuries were frequently caused when logs rolled against or dropped on workers' feet and hands.

Skidding to unloading

Operators of skidders, dozers, loaders, and similar equipment were especially susceptible to eye injuries. In one-fifth of the cases involving equipment operators, the worker suffered an injury to his eyes. Most were cuts and lacerations caused by branches and saplings that whipped into the open cab. Equipment operators were also liable to sprain and sometimes fracture an ankle when they dismounted from their vehicles. Several very serious accidents occurred when tractors overturned and drivers were thrown from their machines. However, most of the injury reports did not give adequate information on the circumstances surrounding these accidents.

Loggers who were loading trucks were subject to four major types of injuries. The most frequent was overexertion caused by lifting, pushing, or pulling logs. The others, in the order of frequency, were: struck by a falling log; caught in, under, or between logs; and falling from an elevation.

Workers were injured when they were struck by logs that rolled off the truck they were loading, and when their hands or feet were caught between or under logs that were being positioned on the truck. Falls often occurred when the worker was standing on the truck and lost his balance (Fig. 4). In several cases, a cant hook that the worker was using pulled loose from the log he was trying to move, causing him to lose his balance and fall.

Unloading trucks is another dangerous activity, especially when saw logs and tree-length timber is being harvested. Nearly one-fourth of all time lost and 10 of the 18 fatalities resulted from injuries received during unloading. These injuries were more serious than others because in half of the cases, truckdrivers were struck by falling logs as they released their loads. Other types of unloading accidents that were serious but less severe occurred when drivers were caught under or between objects, usually logs (20 percent); fell, jumped, or tripped (13.8 percent); or overexerted themselves when unloading logs by hand (10 percent).

Truckdrivers were also injured in accidents caused by tire blowouts, brake failure, shifting loads, and excessive speed on wet roads. In three cases, drivers suffered either sprained or fractured hands when the front wheels of the truck they were driving hit stumps or ruts in the road and forced the steering wheel to spin out of control.

Accidents commonly occurred when equipment was repaired or serviced. Workers moved or lifted fuel drums, skidder tires, dozer blades, and other heavy parts without adequate help, which often resulted in back injuries. Other workers were injured when they slipped and fell from equipment that was being serviced, or while they were sharpening and repairing chain saws, or when overinflated tires exploded.

SAFETY GUIDELINES

This study showed that nearly half of all time lost and almost all fatalities were the result of felling and unloading accidents. The more serious felling accidents happened when trees and limbs dropped on fellers. Unloading accidents occurred less often than those in felling, but tended to be more severe in time lost and number of fatalities. The greatest danger to the driver during unloading was to be struck by a log that rolled off the truck as he released the binders and trip stakes.

Many, perhaps most, of the accidents that happened during felling, unloading, and other logging activities could have been avoided if the workers had followed commonly accepted safety practices. These practices have been incorporated into consensus safety standards developed by representatives from the logging and insurance industries, organized labor, and government agencies (Am. Natl. Stand. Inst. 1971). While the standards do not cover every conceivable hazard in logging, they do establish safety guidelines that will lead to fewer and less costly injuries.

To both save lives and reduce work injury costs, safety programs in the Appalachian region should (1) encourage more intensive safety training, particularly for the young and the inexperienced employees; (2) place renewed emphasis on safety during the late spring and early summer when logging is at its peak; and (3) focus on safety measures for felling and unloading operations.

Felling guides

There are several safety measures that are applicable to felling which could have helped to prevent the injuries reported in this study. These include:

- Plan a retreat path and clear the path before the cut is started. The path should extend diagonally to the rear of the felling area.
- Check the tree to be cut for dead limbs, the lean of the tree, wind conditions, the location of other trees, and other hazards. Exercise proper precautions before starting the cut.
- Make undercuts about one-third the diameter of the tree to guide it and reduce the possibility of its splitting.
- Stop the back cut soon enough to allow for hinge wood to guide the tree and prevent it from prematurely slipping or twisting from the stump.
- Shut off the saw before starting to retreat.
- Fell from the uphill side on terrain where trees are likely to slide or roll, and arrange to keep uphill from previously felled trees.

In addition to these precautionary measures, lodged trees should be pulled to the ground at first opportunity with a skidder or other mechanical equipment. And no one should approach a feller closer than twice the height of trees being felled until the feller has acknowledged the signal of approach.

Unloading guides

Safety during unloading requires the attention and cooperation of both the logger and the purchaser. Unloading trucks carrying saw logs, veneer logs, and tree-length roundwood was generally more hazardous than unloading smaller roundwood. Some safety measures that would help to prevent the more severe unloading accidents reported in this study include:

- Release binders only after the load has been secured by a forklift or similar equipment.
- Release binders only from the side which the unloader operates, except when release is by remote control or when the person releasing the binder is protected by racks, stanchions, or the equivalent.
- Equip trucks used to haul saw logs with a tripping mechanism that releases the bunk stakes from the opposite side, away from where the logs will be dumped.

Publications with more detailed safety guidelines for felling, unloading, and other logging activities can be obtained by request from the American National Standards Institute (1971), the American Pulpwood Association (1971), and A. R. Bentley (1975), which are listed in the Literature Cited.

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Table 1.—Number of injuries in logging by occupation and age of worker, Appalachian area, 1971 and 1974

Occupation	Age										Percent
	<20	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	>59	
Feller	15	62	43	44	53	48	35	39	30	16	37.6
Laborer	16	24	23	13	19	17	13	10	9	9	14.9
Truckdriver	4	17	23	27	25	21	10	11	1	3	13.9
Bucker	6	17	17	9	16	14	9	6	5	5	10.2
Skidder & dozer operator	8	16	18	12	14	6	7	10	3	4	9.6
Chokersetter	14	18	4	7	9	5	4	0	1	4	6.4
Loader operator	0	4	3	4	7	1	2	1	1	0	2.2
Foreman	0	3	5	4	3	1	2	2	4	2	2.5
Other[a]	2	4	3	2	5	2	2	3	0	4	2.6

[a] Not otherwise classified.

Table 2.—Number of injuries in logging by day and hour that accident occurred, Appalachian area, 1971 and 1974

Day	Hour										Total
	Before 8 a.m.	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	After 4 p.m.	
Monday	8	15	22	31	21	8	24	26	13	21	189
Tuesday	3	12	24	33	28	11	18	26	21	13	189
Wednesday	8	8	23	30	27	12	26	34	23	8	199
Thursday	4	10	27	28	17	8	29	29	15	11	178
Friday	3	25	20	27	22	5	17	24	15	14	172
Saturday	0	4	6	7	3	1	3	3	5	1	33
Sunday	2	0	2	0	1	0	1	0	0	1	7

Table 3.—Nonfatal injuries in logging by type of accident and source of injury, Appalachian area, 1971 and 1974

Source	Type				Percent
	Struck by or against	Caught in, under, or between	Fall from elevation or same level	Overexertion	
Power saw	263	0	7	0	24.2
Limb, sapling	174	2	2	0	16.0
Log	108	74	15	36	20.9
Tree	108	1	1	1	10.0
Particles	28	0	0	0	2.5
Hand tools	25	2	2	0	2.6
Chain, cable	21	10	2	1	3.0
Hook, tong	16	1	1	0	1.6
Operating motor vehicles	9	61[a]	5	0	6.7
Ground, rock	4	0	83	0	7.8
Other[b]	7	3	2	23	4.7
Total	763	154	120	61	100.0

[a] Includes 41 injuries such as collision and other operator-related accidents.
[b] Percent total includes 17 injuries not classified by type or source.

Table 4.—Percentage of days lost as a result of nonfatal injuries in logging by type of accident and source of injury, Appalachian area, 1971 and 1974 (N = 39,080 days)

Source	Type				Total[a]
	Struck by or against	Caught in, under, or between	Fall from elevation or same level	Overexertion	
Log	22.9	7.5	0.6	2.6	33.4
Limb, sapling	20.0	.2	.2	.0	20.2
Tree	12.3	*	.0	.0	12.3
Power saw	10.9	.0	.6	.0	11.6
Particles	2.6	.0	.0	.0	2.6
Hook, tong	1.0	.0	.0	.0	1.0
Hand tools	.7	*	.0	.0	.7
Operating motor vehicles	.3	6.8[b]	.2	.0	7.3
Chain, cable	.3	.4	.1	.0	.7
Ground, rock	.2	.0	6.3	.0	6.6
Other[c]	.6	.8	*	1.2	3.4

* Less than 0.1 percent.
[a] Totals may not equal data summed due to rounding.
[b] Includes 5.4 percent days lost due to collisions and other operator-related accidents.
[c] Percent total includes 0.8 percent injuries not classified by type or source.

Table 5.—Nonfatal injuries in logging by type of injury and part of body affected, Appalachian area, 1971 and 1974

Type	Part affected											Percent
	Head, neck	Eye	Back	Trunk	Arm, wrist	Hand	Finger	Leg, ankle	Foot	Toe	Multiple parts	
Amputation	0	0	0	0	0	0	4	2	0	0	0	0.6
Bruise, contusion, concussion	13	11	14	47	13	6	13	54	16	3	24	21.6
Cut, laceration, puncture	49	14	1	9	44	38	43	143	11	8	12	37.5
Fracture	14	0	8	16	10	4	12	57	14	16	8	16.1
Hernia, rupture	0	0	0	10	0	0	0	0	0	0	0	1.0
Strain, sprain, dislocation	1	0	59	18	6	0	2	26	6	0	2	12.1
Irritation from foreign body	0	17	0	0	0	1	0	0	0	0	0	1.8
Multiple injuries	14	0	3	2	3	2	5	8	10	1	35	8.4
Other[a]	2	0	0	0	0	0	1	1	0	0	5	.9
Total	93	42	85	102	76	51	80	291	57	28	86	100.0

[a] Not otherwise classified.

Table 6.—Percentage of days lost as a result of nonfatal injuries in logging by type of injury and part of body affected, Appalachian area, 1971 and 1974 (N = 35,253 days)

Type	Part affected											Total
	Head, neck	Eye	Back	Trunk	Arm, wrist	Hand	Finger	Leg, ankle	Foot	Toe	Multiple parts	
Amputation	0.0	0.0	0.0	0.0	0.0	0.0	2.3	17.0	0.0	0.0	0.0	19.3
Bruise, contusion, concussion	.3	.7	.5	1.2	.1	.1	.3	2.4	.5	.0	.7	6.7
Cut, laceration, puncture	.8	8.0	.0	.3	1.2	1.2	1.6	5.6	1.0	.8	.4	21.0
Fracture	1.8	.0	3.0	2.3	3.2	.1	.8	14.6	3.6	.5	4.2	34.1
Hernia, rupture	.0	.0	.0	1.2	.0	.0	.0	.0	.0	.0	.0	1.2
Strain, sprain, dislocation	.0	.0	4.5	2.0	.1	.0	.1	1.2	.2	.0	.0	8.1
Irritation from foreign body	.0	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	*
Multiple injuries	1.4	.0	.8	.1	.1	.2	.8	.5	1.7	*	3.1	8.9
Other[a]	.0	.0	.0	.0	.0	.0	.1	.2	.0	.0	.3	.6

*Less than 0.1 percent.

Table 7.—Nonfatal injuries in logging by activity of worker and type of accident, Appalachian area, 1971 and 1974

Activity	Type					Percent
	Struck by or against	Caught in, under, or between	Fall from elevation or same level	Overexertion	Other[a]	
Limbing	173	6	4	1	0	18.0
Felling	170	0	5	2	2	17.5
Loading	65	24	29	29	2	14.6
Bucking	94	18	8	1	0	11.9
Operating motor vehicles	39	47[b]	9	2	0	9.5
Setting choker	45	16	7	5	2	7.3
Unloading	34	17	11	9	0	7.0
Present in work area	18	7	31	0	1	5.6
Maintaining equipment	9	4	2	5	4	2.4
Swamping	20	1	1	0	1	2.3
Other[a]	22	5	6	4	3	3.9
Total	689	145	113	58	15	100.0

[a] Includes 15 injuries not classified by type.
[b] Includes 41 accidents such as collisions and other operator-related accidents.

Table 8.—Percentage of days lost as a result of nonfatal injuries in logging by activity of worker and type of accident, Appalachian area, 1971 and 1974 (N = 35,020 days)

Activity	Type					Total[b]
	Struck by or against	Caught in, under, or between	Fall from elevation or same level	Overexertion	Other[a]	
Unloading truck	21.3	1.0	1.8	0.6	0.0	24.7
Felling	20.1	.0	.8	.3	*	21.1
Limbing	10.8	.4	.2	.0	.0	11.2
Bucking	8.1	1.7	.1	.1	.0	10.1
Operating motor vehicles	4.1	6.2[c]	.6	.2	.0	11.0
Loading truck	3.4	1.9	2.7	2.7	.0	10.6
Setting choker	1.7	2.4	.2	*	.2	4.4
Present in work area	.4	.8	1.5	.0	.2	2.9
Swamping	.8	.0	.0	.0	*	.9
Maintaining equipment	.3	.1	.1	.1	.2	.8
Other[a]	.5	1.1	.4	*	.2	2.2

*Less than 0.1 percent.
[a] Includes 15 injuries not classified by type.
[b] Totals may not equal data summed due to rounding.
[c] Includes 6.1 percent lost days due to collisions and other operator-related accidents.

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FEB 2

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FURNITURE CUTTINGS MADE FROM LOGGING RESIDUE:

THE THREE-SIDED CANT SYSTEM

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FEB 6 1979
SCI., TECH. & AGR. DIV.

by Hugh W. Reynolds
and James Schroeder

FOREST SERVICE RESEARCH PAPER NE-417
1978
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MANUSCRIPT RECEIVED FOR PUBLICATION 12 APRIL 1978

Abstract

A new method to make furniture cuttings from the best of logging residues was tested. Bolts 4 through 8 feet long were sawed to three-sided cants. The cants were then resawed to boards and dried. The dried boards were gang ripped and defects removed to obtain clear-one-face cuttings of random width and length. The 6-, 7-, and 8-foot long bolts gave good yields by this system, while the 4- and 5-foot bolts did not.

INTRODUCTION

THERE IS SOME GOOD, small timber left behind as residue after a timber sale. Can this small-diameter residue be quickly and cheaply converted into furniture cuttings? In theory the answer is yes—provided the residue is first converted into cants. In a study to evaluate this process, we found considerable merit to the cant concept provided that three problems could be solved:

1. How to separate the good residue from that of poor quality.
2. How to saw cants to boards quickly and cheaply.
3. How to convert the boards to cuttings cheaply while maintaining a good yield.

To solve these problems, we developed the "three-sided cant system" for making furniture cuttings. We tested the system with oak logging residue from a commercial timber sale on the Monongahela National Forest near Richwood, West Virginia.

PROBLEM 1: HOW TO SEPARATE THE GOOD RESIDUE

Most logging residue is not good enough for furniture use, so the first step is to separate the pulpwood from the better quality residue. We bucked bolts of 4, 5, 6, 7, and 8 feet in length with a 2-inch trim allowance. By bucking out big knots and defects and by reducing sweep, we improved the bolt quality. We also made 4-foot pulpwood bolts which can be of very low quality. When we were not sure of the quality of the residue, we made pulpwood bolts.

The second selection is made at the sawmill. Any bolt that does not have one or more clear faces is sawed to pallet cants (4 by 4, 4 by 6, or 6 by 6 inches). This selection is made quickly and does not interfere with sawmill production.

The bolts to be sawed to three-sided cants are put onto the sawmill carriage with the best face toward the saw. A light slabbing cut is made to expose a face 3 inches wide. Now the final selection is made. If the exposed face is poor, the bolt is sawed to pallet cants. If the face is good, the bolt is sawed as shown in Figure 1.

Figure 1. Sawing three-sided cants.

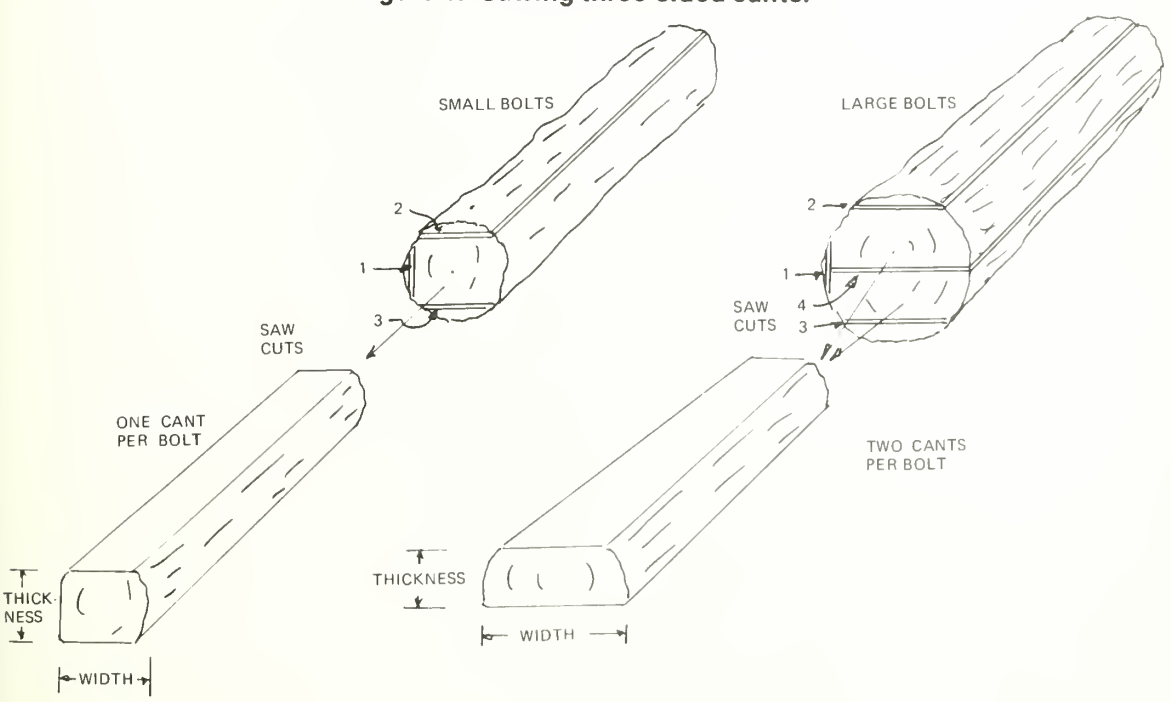


Table 1.—Scale and average size of 3-sided cants from oak bolts, by length and number of bolts

Bolt length (ft)	Number of bolts	Cant scale (fbm)		Cant size (inches)	
		Total	Mean	Height	Width
4	62	604	9.7	5.1	6.2
5	11	156	14.2	5.4	6.2
6	19	373	19.6	5.6	6.6
7	10	232	23.2	5.8	6.8
8	12	385	32.1	5.6	8.1
Total	114	1,750			

There were 114 oak bolts selected by this process and sawed to three-sided cants. The bolts were of small diameter and only three bolts were large enough to yield two cants per bolt. The data are shown in Table 1.

As a usual practice, pallet cants are sold to pallet makers and three-sided cants to furniture makers. If the sawmiller sells the three-sided cants for no more than the pallet cant price per board foot, he will do well because more footage is obtained by less sawing.

PROBLEM 2: HOW TO SAW CANTS TO BOARDS QUICKLY AND CHEAPLY

The second problem is solved by making boards using a circular gang resaw. Circular resaws are made in a variety of styles and sizes. There are resaws with two arbors to saw thick cants to boards in one pass or with one arbor to saw thin cants to boards in one pass. There are one- and two-arbor resaws that saw a few boards from a cant at one time. The cant is repeatedly sent through the resaw to complete the sawing. Approximatey 15 hp per saw is required for resawing hardwoods. Among the possible choices, a three-saw, single-arbor cant resaw best met our requirements for resaw cost, horsepower, and production capacity.

We used a Gross Kerfsaver single-arbor circular gang resaw[1] in this study. Three 18-inch diameter sawblades (3/16-inch kerf) are mounted on the arbor with spacers to give 1 1/32-inch thick boards. The first board is sawed (from the first cut face) between the fence and the first saw, the second board is sawed between the first and second saw, and the third board is sawed between the second and third saw. The machine is open on the left side so that wide cants can be sawed in multiple passes. All boards are sawed parallel to the first cut face (Fig. 1). The top rolls are adjusted in height to accommodate cants from 3 3/4 through 6 inches thick.

This type of resaw gives smooth and accurate sawing with a minimal kerf. The within-board variation of thickness did not exceed .005 (3/64) inch. The between-board variation in average thickness did not exceed .085 (5/64) inch. The first board from a cant had the greatest within-board variation because the first face had been sawed at the sawmill. The greatest cause of between-board variation occurred when the cant face had not been held firmly against the fence.

No board grading was done after resawing. Only those narrow, waney-edged boards that would not give a 1 1/2-inch wide by 12-inch long cutting were rejected; 1,335 board feet of boards were sawed from 1,750 board feet of cants. This is a satisfactory yield of 76 percent.

Excellent drying quality was obtained by starting the air drying immediately after the boards were sawed. The boards were stacked using 1/2-inch thick stickers on 2-foot centers. The 4-foot high by 4-foot wide stacks were tightly banded with polypropylene strapping that kept the packages tight during drying and forklift handling.

The 63 percent initial moisture content dropped to 21 percent during 18 days in the forced air dryer at the Forestry Sciences Laboratory (Cuppett and

[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Craft 1975). The temperature was maintained at 70°F minimum without schedule changes. An 8-day mild schedule in a regular dry kiln was then used to bring the oak to a 6 percent final moisture content. A higher temperature 5-day schedule would have been adequate.

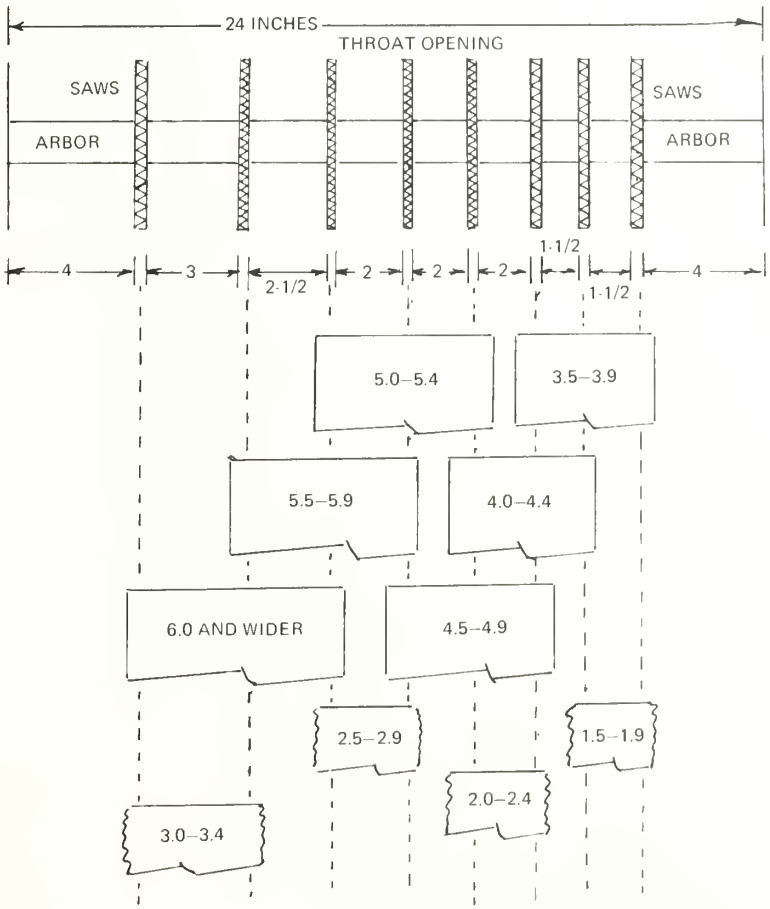
PROBLEM 3: HOW TO CONVERT THE BOARDS TO CUTTINGS CHEAPLY WHILE MAINTAINING A GOOD YIELD

Boards made from cants cannot be processed economically in a conventional rough mill—they are too narrow and short. So we designed a "gang-rip first" rough mill that can be used with automated, commercially available equipment. This new rough mill can reduce the short boards to cuttings at less expense than standard lumber sent through a conventional rough mill. And the yield of parts from short boards remains high.

The kiln-dried boards were first planed on both faces to 7/8-inch thickness. An abrasive planer with 24-grit paper did the job very well. As a result of the smooth, accurate sawing of cants to boards and the good drying, a 5/32-inch allowance for shrinkage and planing was adequate.

The planed boards are then fed into a glue-joint gang ripsaw with a 24-inch throat opening. Eight saws, each having a 1/8-inch kerf, are spaced on the ripsaw arbor as shown in Figure 2. The boards are ripped to strips according to board width. Strip widths are 1.5, 2.0, 2.5, and 3.0 inches. The 10 possibilities used are shown in Figure 2. Boards 1.5 to 3.4 inches wide are ripped to one strip;

Figure 2. Gang ripping kiln dried boards. The boards are ripped to strips according to board width (in inches).



boards 3.5 inches and wider are ripped to two strips. All edgings (regardless of width) are discarded.

Any defect to be removed from the strip is marked on each side, and a mark-sensing chopsaw removes the defects. The quality of cutting required is clear-one-face or better. In some cases, defects are found on the edges of strips. These strips are salvaged by ripping them on a single-blade, glue-joint ripsaw. All cuttings are made random width and length with a 1- by 12-inch minimum.

The yields of cuttings ranged from 47 to 66 percent (Table 2). The board surface area, before gang ripping, was divided into the surface area of the cuttings to find yield percentages. The 4-foot boards gave a lower yield than the longer boards. While the 5-foot boards gave an acceptable yield, little was obtained from automated gang ripping and removing defects—a considerable amount of salvage ripsawing had to be done manually. The 6-foot boards required less salvage ripsawing. The 7- and 8-foot boards were of the quality we were seeking—little salvage ripsawing had to be done to obtain a good yield.

Table 2.—Percentage of cuttings from kiln-dried boards after gang ripping or salvage ripsawing, by board length

Board length (ft)	Gang ripping/ defecting	Salvage	Total
4	23.9	22.9	46.8
5	14.6	43.6	58.2
6	23.6	33.9	57.5
7	44.1	22.7	66.8
8	45.9	19.7	65.6

If the gang-rip rough mill is to solve the problem of how to get cuttings cheaply while maintaining a good yield, the yield should be over 50 percent, and most of the cuttings should be obtained by automatic gang ripping and crosscutting. Also, it is very desirable to have a good proportion of long cuttings.

Table 3.—Percentage of total yield of long and short cuttings, by board length

Board length (ft)	Long cuttings[a]	Short cuttings[b]
4	10	90
5	40	60
6	36	64
7	32	68
8	39	61

[a]40 inches and longer.
[b]Less than 40 inches long.

The 4-foot boards had slightly less than 50 percent yield and half of that yield was made automatically, but only 10 percent of the cuttings were long (Table 3). The 5-foot boards had a satisfactory yield of 58.2 percent, and 40 percent of the cuttings were long—but very little of the yield was made automatically. The 6-, 7-, and 8-foot boards had good yields with one-third in long cuttings, and most of that yield was made automatically. So we can say that the gang-rip rough mill was satisfactory for 6-, 7-, and 8-foot boards but not for the 4- and 5-foot boards.

CONCLUSIONS

Logging residue is plentiful and cheap but of low quality. By making 6-, 7-, and 8-foot bolts, the poorest residue is not used. The best bolts are sawed to three-sided cants and the poorer bolts to pallet cants. The three-sided cants are sawed to boards, the boards are dried, and are then made to clear-one-face or better cuttings in an automated rough mill. Board yields are approximately 60 percent with more than one-third of the cuttings 40 inches or longer.

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EFFECTS OF WATERING AND FERTILIZATION ON CARBOHYDRATE RESERVES IN SUGAR MAPLE SEEDLINGS

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by Clayton M. Carl, Jr.,
John R. Donnelly,
and Boyd W. Post

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Abstract

Sugar maple seedlings, grown under three nutrient and three moisture levels, were analyzed after three growing seasons for starch and ethanol-soluble sugars. Analytical procedures are detailed in the appendix. Fertilization did not affect carbohydrate levels in stems or roots. Water stress caused a significant reduction in the amount of carbohydrates in stems and roots; it had no significant effect on carbohydrate concentration in roots, but it significantly increased carbohydrate concentration in stems.

INTRODUCTION

Because plants rely on stored carbohydrates for shoot elongation in the spring, cultural practices that promote carbohydrate accumulation would be expected to stimulate subsequent growth. In a previous paper (Carl et al. 1973), we described some of the effects soil mosture and nutrient levels had on seedling growth of sugar maple (*Acer saccharum* Marsh.). In this report, we provide information on the status of reserve carbohydrates (starch and ethanol-soluble sugars) at the end of the third growing season for these same seedlings.

METHODS

We grew half-sib sugar maple seedlings in 20-cm plastic pots filled with soil from the B horizon of a Paxton loam and imposed three nutrient and three soil moisture levels in all combinations (nine treatments) with nine seedlings per treatment. The three nutrient levels were: (1) low—no nutrient added; (2) medium—1-liter equivalent of a complete Hoagland solution added to each pot; and (3) high—2-liter equivalents of a complete Hoagland solution added to each pot. The three levels of soil moisture were: (1) low—soil moisture maintained at 8 to 18 percent; (2) medium—soil moisture maintained at 18 to 28 percent; and (3) high—soil moisture maintained at 28 to 38 percent.

We harvested the seedlings after leaf-fall of the third growing season, and analyzed stems and roots separately for starch and ethanol-soluble sugar content. Analytical procedures are detailed in the appendix.

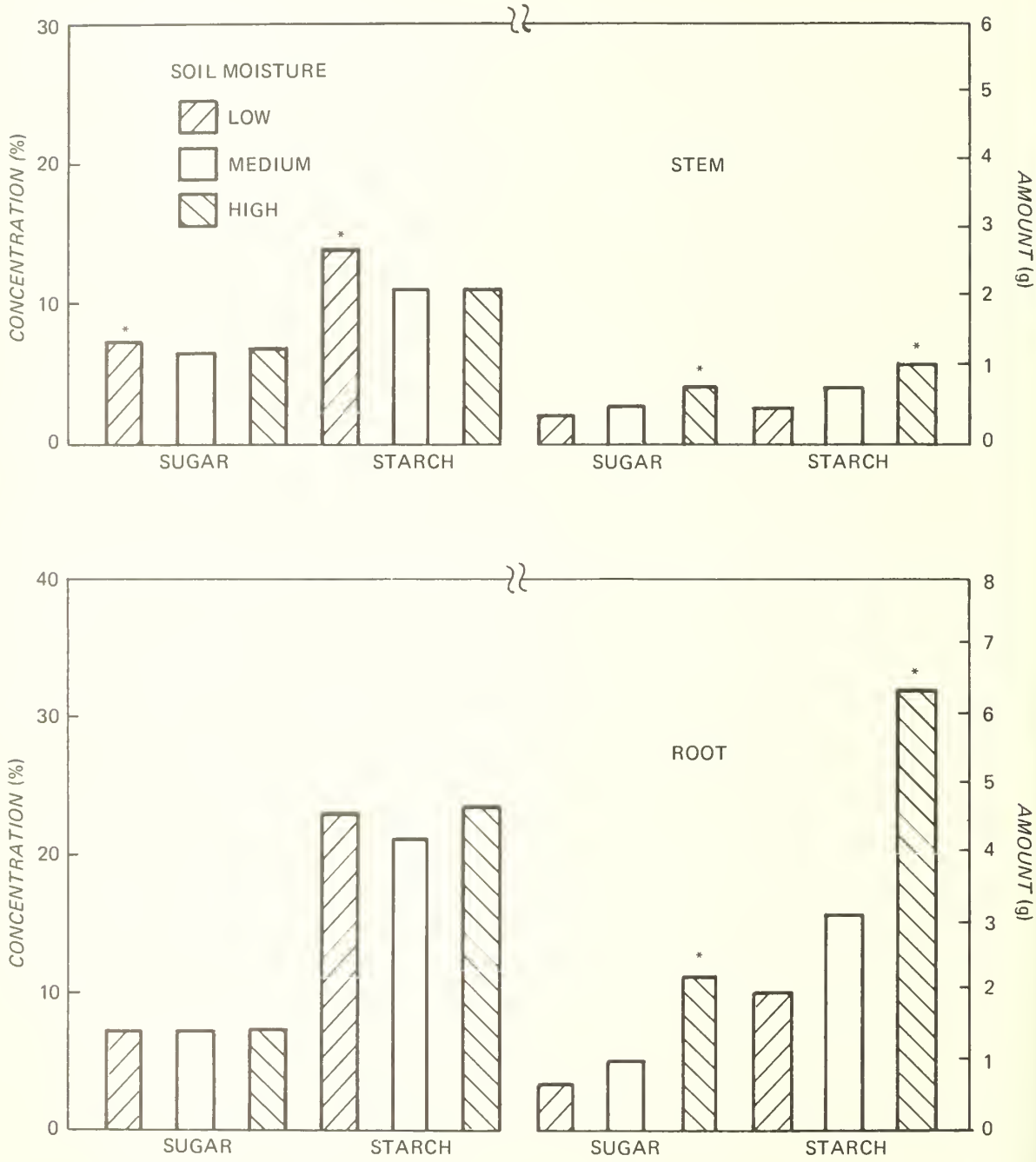
RESULTS AND DISCUSSION

Carbohydrate levels are commonly reported in terms of concentration (percent dry weight), but this may be misleading because changes in carbohydrate levels may be masked by differences in plant biomass. Consequently, we express sugar and starch content both in concentration and in absolute amounts (Table 1).

Table 1.—Weight (in grams) and concentration (in percent) of starch and ethanol-soluble sugar levels in 3-year-old sugar maple seedlings, by treatment.

Treatment	Stem sugar		Stem starch		Root sugar		Root starch	
	Concn	Wt	Concn	Wt	Concn	Wt	Concn	Wt
Low nutrients								
Low H_2O	7.3	13.3	15.9	29.8	6.6	46.8	23.4	165.5
Med H_2O	6.1	51.3	9.5	76.6	6.7	144.8	22.5	461.8
High H_2O	5.8	50.4	11.1	90.2	7.6	178.2	24.2	558.4
Medium nutrients								
Low H_2O	7.0	29.2	11.6	50.6	7.6	91.6	21.8	245.7
Med H_2O	6.4	38.7	9.0	53.9	7.6	104.7	20.7	269.8
High H_2O	6.8	83.9	10.4	118.1	7.1	212.7	21.9	577.7
High nutrients								
Low H_2O	7.6	16.0	13.0	31.4	6.9	58.4	22.2	178.6
Med H_2O	6.0	28.4	12.7	58.7	6.8	63.8	19.5	205.2
High H_2O	6.3	78.0	9.5	103.2	7.1	237.3	23.4	763.0

Figure 1.—Effect of soil moisture on reserve carbohydrates in 3-year-old sugar maple stems and roots. An asterisk indicates that the value for that watering level is significantly different from the other two levels according to the Student-Newman-Kuels test.



Fertilizers had no significant effect on the concentration or amount of carbohydrates in stems or roots, and there were no significant interactions between fertilizers and water. There was, however, a good deal of variation within treatments, and this may have masked significance. In 1973 we reported (Carl et al.) that fertilizers did not significantly improve growth of these seedlings. As hypothesized in that paper, the potting soil and/or the added water may have contained sufficient nutrients to mask the effects of the additional fertilizer.

Watering had a significant effect on carbohydrate reserves. Stems and roots grown under low water levels had less than half as much sugar and starch as did those grown in moist soil (Fig. 1). This is undoubtedly the result of reduced photosynthesis in seedlings grown under severe water stress (Kramer 1969). And, because subsequent growth depends upon carbohydrate reserves, well-watered seedlings were substantially larger (Carl et al. 1973).

In contrast to its inhibitory effects on the weight of carbohydrate reserves, water stress caused a small but statistically significant increase in the concentration of sugar and starch in the stem (Fig. 1). Normally, a substantial portion of the carbohydrates produced is assimilated into secondary plant constituents such as cellulose. In stems, severe water stress appears to inhibit the conversion of carbohydrates into these secondary products more than it inhibits the production of carbohydrates; consequently, the concentration of stem carbohydrates increases. Brown and Blaser (1970) reached a similar conclusion is a study of orchard grass (*Dactylis glomerata*). In maple roots, the accumulation of carbohydrates and the assimilation of secondary products were equally inhibited by water stress, for treatment had no significant effect on root sugar or starch concentration.

Restricting soil moisture may be of benefit for nursery-grown seedlings in that it may cause a slight increase in stem carbohydrate concentration which may make the seedlings more resistant to frost injury (Levitt 1956). If sugar maple seedlings grown under very moist conditions are indeed more susceptible to frost injury, this can probably be corrected by reducing the watering schedule in late summer.

Appendix
Procedures for Quantitative Analysis of Ethanol-Soluble Sugars and Starch

TREATMENT OF PLANT MATERIAL

Plant material is frozen immediately after collection (to prevent interconversion of carbohydrates) and stored at $-15°C$. Another method of preparing samples is to cut the material into small pieces, place approximately 2-g samples in glass jars, and fix the samples with hot 80% ethanol. The jars are then capped and stored at room temperature until samples are analyzed; all material not included in the sample is dried and weighed for subsequent calculation of total amounts of carbohydrates.

EXTRACTION AND ANALYSIS

Extraction and colorimetric procedures have been adapted from Morris (1948), Hodge and Hofreiter (1960), Horwitz (1960), Ward and Johnston (1962), and Witherell (1963).

Ethanol-soluble sugars

1a. If the material has been frozen, grind it in a Wiley mill, using a 10-mesh screen. Place approximately 2 g of the ground material in a 500-ml round-bottomed flask and add approximately 100 ml of 80% ethanol.

1b. If the material has been stored in ethanol, pour the entire contents (plant material plus ethanol) into a 500-ml round-bottomed flask and add enough ethanol to make approximately 100 ml.

2. Place the flask in a heating mantle, connect it to a condenser, and reflux the ethanol for 1 h, with the transformer adjusted so the ethanol will boil. A series of these units can be set up so that several samples can be analyzed simultaneously.

3. Weigh a 60-ml fritted glass funnel that has been oven dried and cooled in a desiccator.

4. Decant the ethanol through the funnel and collect it in a filtering flask. Use a vacuum to facilitate filtration; a water aspirator is satisfactory for all vacuum needs.
5. Add 50 ml of 80% ethanol to the residue in the round-bottomed flask, and reflux for 1/2 h.
6. Repeat Steps 4 and 5. Collect all the filtrate in the same flask.
7. Pour the entire contents of the round-bottomed flask into the funnel and rinse the flask, residue, and funnel with 80% ethanol. Save the filtrate and residue.
8. Oven dry the fritted funnel containing the residue, cool it in a desiccator, and weigh. Save the residue for starch analysis.
9. Transfer the filtrate (Step 7) to an evaporating flask, and reduce the filtrate to about 15 to 20 ml on a flash evaporator. The flash evaporator should be operated with the water-bath temperature at 40°C, and at maximum vacuum.
10. Transfer the concentrated filtrate to a 50-ml volumetric flask.
11. Rinse the evaporating flask several times with small quantities of distilled water. Add each rinse to the volumetric flask.
12. Make the filtrate up to 50 ml with distilled water.
13. Weigh 2 g of Rexyn 101[1] and 3 g of Rexyn 203[1] into a 250-ml Erlenmeyer flask, and add the 50 ml of filtrate.
14. Clarify the filtrate by shaking gently on a mechanical shaker for 3 h.
15. Pass the filtrate through a 60-ml fritted funnel into a 125-ml filtering flask, using vacuum.
16. Transfer a 5-ml aliquot of the clarified filtrate into a 200-ml volumetric flask, and make up to volume with distilled water.
17. Place a 5-ml eliquot of the 200-ml dilution into each of two 1-in colorimeter tubes, and prepare a reference blank tube containing 5 ml of distilled water.
18. Place the tubes in a cold water bath, and add 10 ml of anthrone reagent[2] gently down the side of each tube, so that two separate layers are formed. A repeating pipet can be used to save time.
19. After all the tubes have been prepared, shake them thoroughly, and place them in a boiling water bath for 15 min. Evaporation can be reduced by covering the mouth of each tube with a large glass marble.
20. Cool the samples quickly to room temperature in a cold water bath, wipe the tubes clean, and read percent transmittance on a colorimeter set at 540 nm. Use the reference blank to adjust the colorimeter for 100% transmittance. If solutions are too dark for accurate colorimetric readings, adjust the aliquot size (Step 16); aliquot size must be known for subsequent calculations.

Starch

1. Grind the coarse residue obtained from the sugar extraction (Step 8 of sugar analysis).
2. Weigh out a known amount (approximately 0.15 g) of the ground residue in a 50-ml round-bottomed polyethylene centrifuge tube.
3. Place a magnetic stir rod in the centrifuge tube.
4. Add 10 ml of 4.7N perchloric acid, drop by drop, from a buret, stirring vigorously on a magnetic stirrer for 10 min.
5. Centrifuge at approximately 3,700 rpm for 5 min.
6. Decant the liquid, filtering through a 15-ml coarse fritted funnel, into a chilled 125-ml filtering flask immersed in ice water. Use vacuum to facilitate filtration.
7. Repeat Steps 4, 5, and 6 twice more. Collect all the filtrate in the same filtering flask.
8. Transfer the total filtrate to a 50-ml volumetric flask, and make up to volume with distilled water.
9. Measure a 5-ml aliquot into another 50-ml volumetric flask. Prepare a separate reference flask by adding 5 ml of distilled water to a 50-ml volumetric flask. Treat the sample and reference flasks as follows:

[1] Fisher chemicals. The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U. S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

[2] Prepare anthrone reagent by adding 1 gm anthrone powder to a 500-ml volumetric flask, and make up to volume with 95% sulfuric acid.

10. Add a drop of phenolphthalein indicator (1% solution in 95% ethanol).
11. Add 2N sodium hydroxide until a pink color appears.
12. Add 2N acetic acid, a drop at a time, until pink color disappears, and then add an additional 2.5 ml.
13. Add 0.5 ml of 10% potassium iodide solution. Use a repeating pipet.
14. Add 5.0 ml of 0.0125N potassium iodate solution. Use a repeating pipet.
15. Shake the flasks to mix the contents thoroughly. Wait 5 min, and make up to volume with distilled water.
16. Pour about 5 ml of the liquid from each flask into each of two 1/2-in colorimeter tubes, and read percent transmittance with the colorimeter set at 590 nm. Use the reference tube to adjust the colorimeter for 100% transmittance. If solution is too dark for accurate colorimetric readings, adjust the aliquot size (Step 9); aliquot size must be known for subsequent calculations.

STANDARDS AND CALCULATIONS

Sugar

Prepare a 0.1 mg/ml sugar solution by adding 100 mg of sucrose to a 1,000-ml volumetric flask, and make up to volume with distilled water. Prepare a series of known sugar concentrations by adding aliquots (0 to 50 ml) of this solution to 50-ml volumetric flasks, and make up to volume with distilled water.

Pour two 5-ml samples of each standard concentration into 1-in colorimeter tubes. Then treat according to Steps 18, 19, and 20 of the sugar analysis.

To calculate the sugar content in a sample, relate the percent transmittance readings obtained from the sample material to those obtained from the standards. This can be done graphically or mathematically. Because of the dilution in Steps 16 and 17 of the sugar analysis, this value must be multiplied by a conversion factor to determine the total amounts of sugar in the sample.

Starch

Since starches from different plant species vary in their amylase content, it would be desirable to use as a standard a sample of pure starch from the species being analyzed (Ward and Johnston 1962). Nielsen (1943) gives a method for extracting starch for standardization if it is desired. If relative values for a particular species are satisfactory, standards can be prepared from potato starch. This is the procedure we used.

Prepare a 1.0 mg/ml starch solution by adding 20 ml of 4.7N perchloric acid to 100 mg of starch in a beaker. Stir for 10 min (make sure starch is completely dissolved), and make up to volume in a 100-ml volumetric flask. Place a series of aliquots from 0.2 to 3.0 ml of this solution in 50-ml volumetric flasks, and proceed as outlined in the starch analysis, beginning with Step 10.

Methods for calculating starch concentration and amount are similar to those outlined for sugar. The only difference is in the method of obtaining total sample weight. Sugars have already been removed before the starch samples are weighed; therefore, the sample weight obtained in Step 2 of the starch analysis sould be corrected for this.

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A Quality Classification System for Young Hardwood Trees—the First Step in Predicting Future Products

by David L. Sonderman
and Robert L. Brisbin

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Abstract

Forest managers have no objective way to determine the relative value of culturally treated forest stands in terms of product potential. This paper describes the first step in the development of a quality classification system based on the measurement of individual tree characteristics for young hardwood stands.

INTRODUCTION

In the past, many studies have been made to determine log and tree quality in mature timber. But one important aspect of timber quality research has not received adequate attention—estimating the quality of young hardwood stands and predicting their future product potential. Boyce and Carpenter (1968) described a technique for grading hardwood growing stock trees in terms of potential log grades. The system is based on the correlation between the number of surface defects and the probability that the future butt log will be a certain grade. Ward (1964) developed a clear volume index to evaluate the potential log grade of young trees. However, both of these systems are based on standard log grades that are applicable only to factory lumber yields. Two additional papers (McCormack 1957, Barger and Ffolliott 1970) describe techniques that relate the measurement of individual tree characteristics to current potential products for conifers, but these systems do not consider the quantification of future product potential. Forest managers, silviculturists, and economists need to know the quality of young stands so that their current and future value can be estimated.

Recently a multidiscipline project was begun to evaluate the economic implications of silvicultural practices in the central hardwoods. As a part of this project, we have begun a study to develop a quality classification system based on empirical measurements of individual tree characteristics that can be related to the future product potential of a stand.

This paper presents our ideas on how the development of such a system should be approached; it is the first step in quantifying tree characteristics that are important to the development of quality trees.

We believe that the classification system should not be oriented to specific current products, but should be based on a biological description of the tree. End-product specifications and utilization standards change; therefore a classification system that assigns grades based on current products soon becomes obsolete. However, if each tree characteristic can be ascribed a numerical value and aggregated for the stand, then these values can be interpreted in terms of products at any point, regardless of a change in standards.

THE STUDY

To test our approach and to develop techniques to describe tree characteristics related to quality potential, we established our study in timber stands on the Vinton Furnace Experimental Forest in southern Ohio. Detailed records of the history of the stand are available, and they provided information on the natural variation in the stands and were an aid in establishing study plots. These stands are primarily of mixed oaks, black cherry, red and sugar maple, white ash, elm, hickory, and yellow-poplar.

The study area is an 8-acre hardwood stand that regenerated 21 years ago after it was completely clearcut. Thirty 1/10-acre plots were established, and all trees larger than 3.5 inches dbh were numbered and then measured for specific characteris-

tics. All trees less than 3.5 inches dbh were tabulated by 1-inch dbh classes for each species.

Groups of plots were assigned treatments that represented 70, 50, and 30 percent stocking, crop tree release, and a control. After the treatments, the residual trees were again measured. The measurements of these trees are the basis for evaluating changes in the individual tree characteristics that result from stocking treatments. (Additional stands are also being treated by various cultural methods, and will be reported on later).

Tree characteristics and their measurement

We have tried to quantify the tree characteristics that we feel will affect potential product quality and quantity. Because we envision a total evaluation system, these characteristics must be relatively easy to measure or estimate under operating conditions. These characteristics and their interactions can then be integrated to form a quality profile that is more descriptive of a tree or stand than just a single, numerical grade that is assigned in the field. The interpretation of these variables and their significance in terms of future products will depend on the species composition and age of the stand. However, the characteristics and assigned values will provide a common framework in which to make the interpretations. Additional studies on the changes in tree characteristics over time will be required to more accurately correlate the numerical value assigned to the characteristic and the future product potential.

The characteristics that we initially selected as variables and which we measured or estimated for our quality classification system are:

Dbh (diameter at breast height). All trees with diameters ranging from 3.5 to 12.0 inches were measured to the nearest 1/10 inch. Trees with smaller diameters were not measured for stem characteristics.

Crown class. Trees were classified as dominant, codominant, intermediate, or suppressed. Generally, the dominant and codominant trees will remain in the stand and will be the final crop trees. However, there may be situations where the intermediate and suppressed trees will be more desirable, particularly if tolerant species are abundant in the stand. Therefore, crown class along with species composition is an important indicator of gross stand quality.

Crown ratio. This is the ratio of live crown length to total tree height. This measurement combined with the tally of limb-related defects in the bottom 16 feet of the tree will provide a complete picture of the entire stem in terms of limb characteristics.

Total height. Total height is measured in feet from a 1-foot stump to the top of the tree. We chose total height rather than height to some minimum diameter because it can be more easily and consistently measured. Total height is needed to compute volume as well as to determine bole length, both of which are related to product potential.

Fork height. Fork height is defined as the length in feet from a 1-foot stump to the junction of the first main fork; this measurement reflects the primary bole length. Also, cross-grain and tension wood are often associated with forks, so they are important indicators of wood quality.

Sweep and crook, Sweep and crook are quantified by measuring the number of inches that the tree bole deviates from a straight line in the butt 16 feet of the tree. These characteristics are important factors because they indicate the possible development of tension wood which results in warp and cup in end products. The general quality of the stand will be increased if trees with excessive sweep and crook are removed at an early age.

Table 1a.—Percentage of study trees that show quality indicators.

Characteristic	Percent
Crown class	
Dominant	30
Codominant	55
Intermediate	12
Suppressed	3
Forks[a]	12
Sweep and crook (inches)[a]	
1-2	30
3-4	35
5-6	14
7-8	7
9+	8
Faces affected by rot and seam (number)[a]	
One	7
Two	2
Three	<.5
Four	<.5

[a] In butt 16-foot section.

Table 1b.—Percentage of trees with live and dead limbs, by section.

Section	Live limbs (number)				Dead limbs (number)			
1-2		3-4	5-8	9+	1-2	3-4	5-8	9+
Butt 8-feet	<.5	—	—	—	30	15	11	1
Upper 8-feet	3	2	1	—	25	20	31	8

Table 1c.—Percentage of trees with limb overgrowths and epicormic branches.

Defect (number)	Percent
Overgrowths[a]	
1-3	18
4-6	20
7+	36
Overgrowths with associated epicormics[a]	
1-3	10
4-6	1
7+	1
Epicormics[b]	
1-6	8
7+	1
Epicormics[c]	
1-6	11
7+	2

[a] Butt 16-foot section.
[b] Butt 8-foot section.
[c] Upper 8-foot section.

Rot and seams. These are quantified by visually squaring the butt 16 feet of the tree into four faces so oriented that most indications of rot and seams appear in one of the faces. The number of faces affected is then counted and the length of the visible defect is measured in feet. Trees that contain visible rot and seams are poor candidates for survival in the residual stands. Overgrown rot and seams usually cover up more serious trouble as the tree matures.

Limb count and limb-related defects. Each 8-foot section of the butt 16 feet of the tree, which is the most important portion when considering quality indicators, is evaluated. The limbs that are $\geq$ 1/3 inch in diameter at the point of attachment to the stem are quantified as follows:

1) All live and dead limbs are counted and recorded separately.

2) The diameters of the single largest live and single largest dead limb are measured to the nearest 1/4 inch.

There are two types of limb-related surface defects that can result in product defects in larger trees—limb overgrowths and epicormic branches. For the purpose of this study, we quantified these two characteristics by counting the number of overgrowths and epicormic branches in each 8-foot section of the butt 16 feet of the stem.

These characteristics, selected because of their consistent relationship with use requirements for most products, should reflect the utility of a tree for veneer, lumber, structural timbers, pulp, etc.

Development of a tree classification system

The individual trees that have been measured and tallied provide a descriptive record that can be aggregated to form a profile of an entire stand. We have done this for the initial study area (Table 1 a, b, c).

Additional information such as tree size and species within treatment area, average size of live and dead limbs, number of limb-related defects per square foot of surface area, and average crown ratio can also be developed from the basic data and summarized to provide a basis for a qualitative estimate of the product potential of the stand. By accumulating data on the changes in tree characteristics over a period of time, functions with associated probabilities can be developed as a basis to make quantitative estimates of the future product potential of the stand.

APPLICATION OF THE SYSTEM

A quality classification system for young trees based on a single numerical grade is not sufficient. However, for some uses of this information, it may be desirable to aggregate the individual characteristics in such a way so that a relative index could be expressed for a group of trees within a stand.

We have developed a somewhat arbitrary index system for the purpose of quickly ranking sample trees as good, medium, or poor. This index is based on crown class, stem curvature, and number of limbs. We combined the individual indexes (Table 2) to establish relative quality classes:

Sum of individual indexes	*Relative quality class*
10–12	Good
8–9	Medium
1–7	Poor

We are using this relative quality index as a stratification technique for selecting sample trees within each treatment category for more detailed measurements.

After the detailed measurements have been made on the sample trees, descriptive statistics can be developed for the group of trees. For example, Tables 3 a, b and c list several of the descriptive statistics for the groups of plots that were thinned to the 50 percent stocking level. These data indicate why the trees are graded as good, medium, or poor (index class 1, 2 and 3), and show the distribution of the individual characteristics both before and after treatment. This information could also be analyzed by species groups and tree size.

The relative quality class can also be used to show the gross changes that result from treating a stand or group of plots (Table 4). Thinning to a 30 percent stocking level resulted in the highest increases of quality trees; however, these differences can be expected since the 70 percent stocking treatment caused very little change in the number of residual stems.

Table 2.—Index of numerical values assigned to selected tree characteristics to determine tree quality.

Characteristic	Value
Crown class	
Dominant	4
Codominant	3
Intermediate	2
Suppressed	1
Sweep and crook (deviation in inches)[a]	
1	4
2-4	3
5-6	2
7-8	1
9+	0
Limb count (no. live and dead limbs $\geq$ 1/3 inch)	
1-2	4
3-4	3
5-8	2
9-16	1
17+	0

[a] If tree has forks, rot or seams then numerical value = 0.

The indexing system provides a technique for ranking the relative quality of trees that exhibit high variability within and between stands. The indexes for the individual characteristics could be weighted in various ways to satisfy specific objectives. The more detailed summary of individual characteristics, combined with information on their development over a period of time, will indicate the potential products that the stand may yield.

In future studies we plan to investigate sampling methods for applying the quality classification system under operating conditions and to develop numerical techniques for relating the array of tree characteristics to future product potential. The ultimate goal is to develop techniques to merge a numerical system of this type with volume estimation equations so that quality and volume changes can be evaluated simultaneously.

Table 3a.—Percentage of trees in relative quality class before and after treatment on plots thinned to 50 percent stocking, by quality characteristic.

Characteristic	Quality class					
	Good		Medium		Poor	
	Before	After	Before	After	Before	After
Crown class						
Dominant	37	37	46	50	3	8
Codominant	63	63	50	45	59	77
Intermediate	—	—	4	5	28	15
Suppressed	—	—	—	—	10	—
Forks	—	—	—	—	41	23
Sweep and crook (inches)						
1-2	47	47	50	50	31	38
3-4	53	53	44	47	31	31
5-6	—	—	6	3	31	23
7-8	—	—	—	—	7	8
9+	—	—	—	—	—	—
Faces affected by rot and seams (number)						
One	—	—	—	—	7	7
Two	—	—	—	—	—	—
Three	—	—	—	—	—	—
Four	—	—	—	—	—	—

Table 3b.—Percentage of trees in relative quality class before and after treatment on plots thinned to 50 percent stocking, by live and dead limb count.

Limb count	Quality class					
	Good		Medium		Poor	
	Before	After	Before	After	Before	After
In butt 8-feet						
Live						
1-2	—	—	—	—	3	—
3-4	—	—	—	—	—	—
5-8	—	—	—	—	—	—
9+	—	—	—	—	—	—
Dead						
1-2	32	32	42	42	17	23
3-4	10	10	21	26	31	23
5-8	—	—	15	8	17	30
9+	—	—	2	3	—	—
In upper 8-feet						
Live						
1-2	5	5	2	3	7	—
3-4	—	—	2	—	7	8
5-8	—	—	2	3	4	—
9+	—	—	—	—	—	—
Dead						
1-2	47	47	10	3	28	8
3-4	26	26	23	21	28	38
5-8	10	10	54	63	24	31
9+	—	—	10	10	17	23

Table 3c.—Percentage of trees in relative quality class before and after treatment on plots thinned to 50 percent stocking, by defect.

Defect (number)	Quality class					
	Good		Medium		Poor	
	Before	After	Before	After	Before	After
Overgrowths (butt 16-feet)						
1-3	16	16	12	13	4	8
4-6	16	16	17	18	10	15
7+	5	5	2	3	14	8
Epicormics (butt 8-feet)						
1-6	21	21	10	8	10	15
7+	—	—	2	3	4	8
Epicormics (upper 8-feet)						
1-6	10	10	6	5	14	15
7+	5	5	—	—	—	—

Table 4.—Percentage of trees in each relative quality class before and after treatment.

Treatment	Number of plots	Quality Class								
		Good		Percent change	Medium		Percent change	Poor		Percent change
		Before	After		Before	After		Before	After	
Thin to 70% stocking	6	22	23	+1	44	45	+1	34	32	−2
Thin to 50% stocking	5	20	27	+7	50	54	+4	30	19	−11
Thin to 30% stocking	6	26	37	+11	32	37	+5	42	26	−16
Crop tree release	8	15	21	+6	38	40	+2	47	39	−8
Control	5	26	26	0	35	35	0	39	39	0

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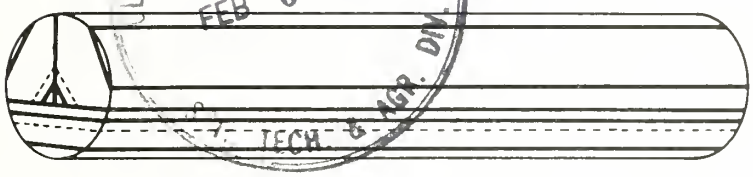

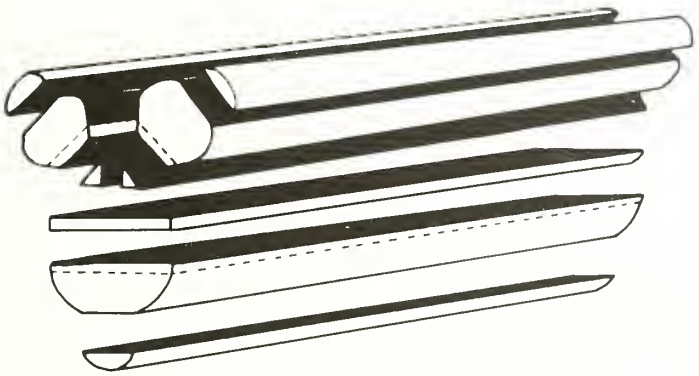

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Abstract

Veneer quality logs of black cherry and northern red oak from northern Pennsylvania were converted into sliced face veneer. The percentage yield of veneer for cherry was greater than oak due to tree form. Thirty-four percent of the total log volume of oak became chippable or fuel residue, but only 29 percent of cherry. Where and how this loss of material occurs in the veneering process is discussed.

INTRODUCTION

Much research has been done on veneering hardwoods, but very little work has been done on the relationship of products yielded during the veneering process, or the factors that affect these yields. In this study I have examined the volume relationship from the sawing of the log into flitches through the steaming, slicing, drying, and grading of the veneer. This is the type of information that log buyers and mill managers need to determine their recovery efficiency. It will help to estimate the percentage of yield of products as well as the portion of the log that is only used as chips or boiler fuel.

THE STUDY

Sample data

The data are from a veneer study conducted on the Allegheny National Forest in northern Pennsylvania. Samples of both black cherry and northern red oak were selected and graded using the interim Forest Service veneer-log grades as a guide (Rast et al. 1973). After felling, the veneer portion of each tree was bucked into log lengths of 8, 9, 10, or 12 feet. There were 98 cherry logs and 86 oak. The surface and ends of each veneer log were diagramed to provide a permanent record of the log defects. The length to the nearest inch and the diameter to the nearest 1/10-inch were measured and recorded. Also, a numbering system was used so that the veneer could be traced back to the flitch, log, position within the log, and the tree.

At the veneer plant, the logs were debarked and sawed into flitches. The number of flitches per log was determined by diameter specifications used at the veneer plant, but the breakdown for this study did not follow the specifications exactly—there was some overlap:

Flitches per log	*Diameter range (inches)*
2	*12 to 15*
3	*14 to 17*
4	*16+*

The flitches were heated in vats of water for about 36 hours, then end trimmed, and the faces cleaned with a hand-held rotary planer. Next, the flitches were sliced, and the veneer was dried and bound into "books."

Volume determination by categories

Figures 1a, 1b, and 1c illustrate how the logs were cut into flitches, and show the different products that resulted. During each phase of the veneer production, measurements were taken at various intervals to determine the volume of the products. All measurements (Tables 1 - 8, Appendix) are of green volume except a portion of the scrap veneer and the veneer itself, which are dry volume. Following is an explanation of the measurements and how they were obtained:

1. Volume of individual logs, in cubic feet. Diameter and length measurements were taken in the field, and the following formula was used to determine total log volume. Since these were veneer logs, there

Figure 1a.—2-flitch log.

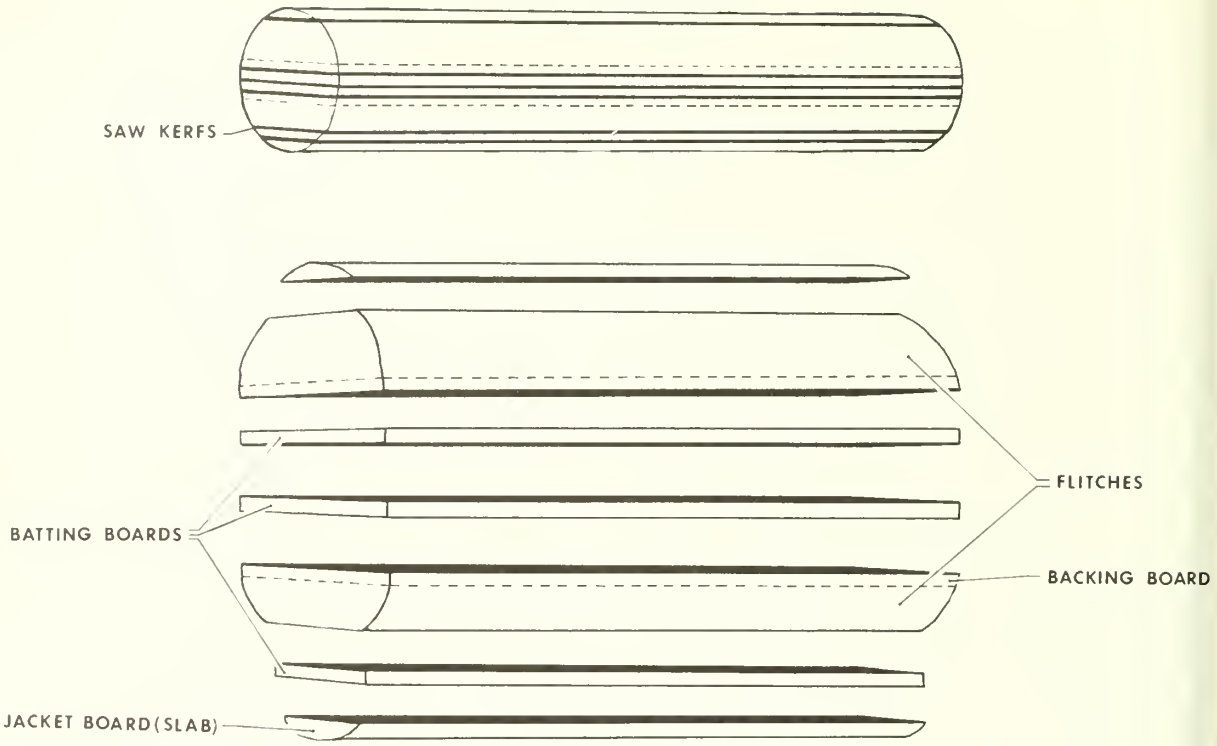


Figure 1b.—3-flitch log.

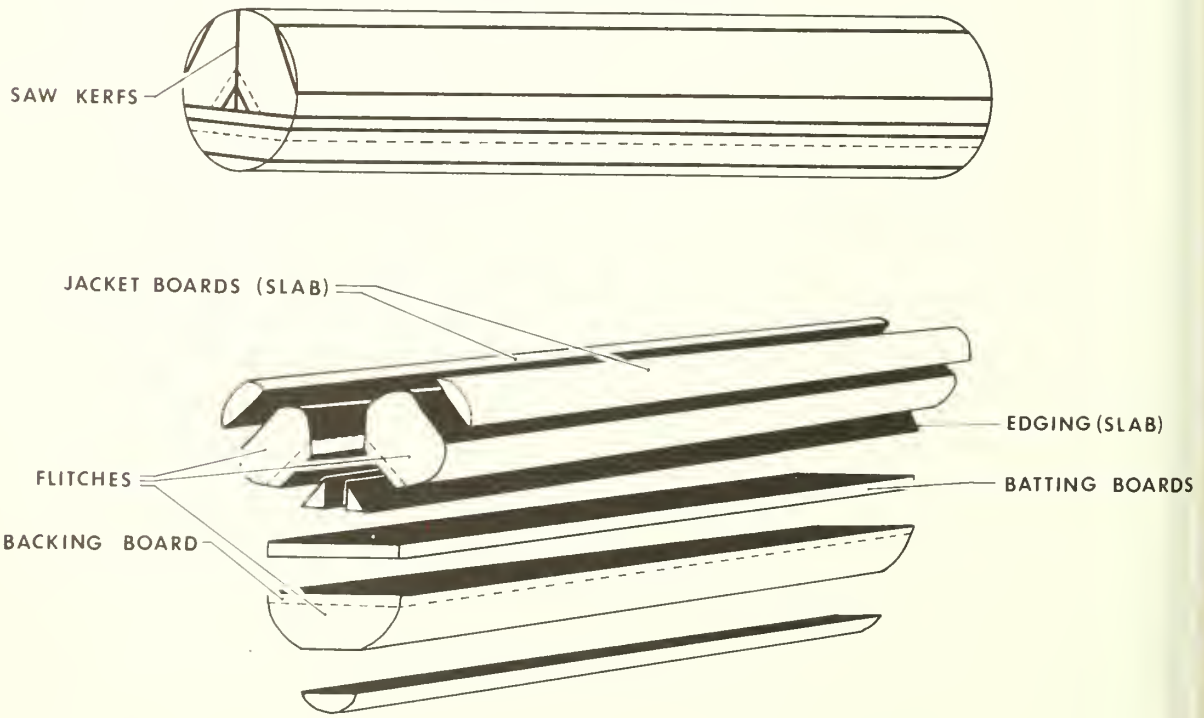
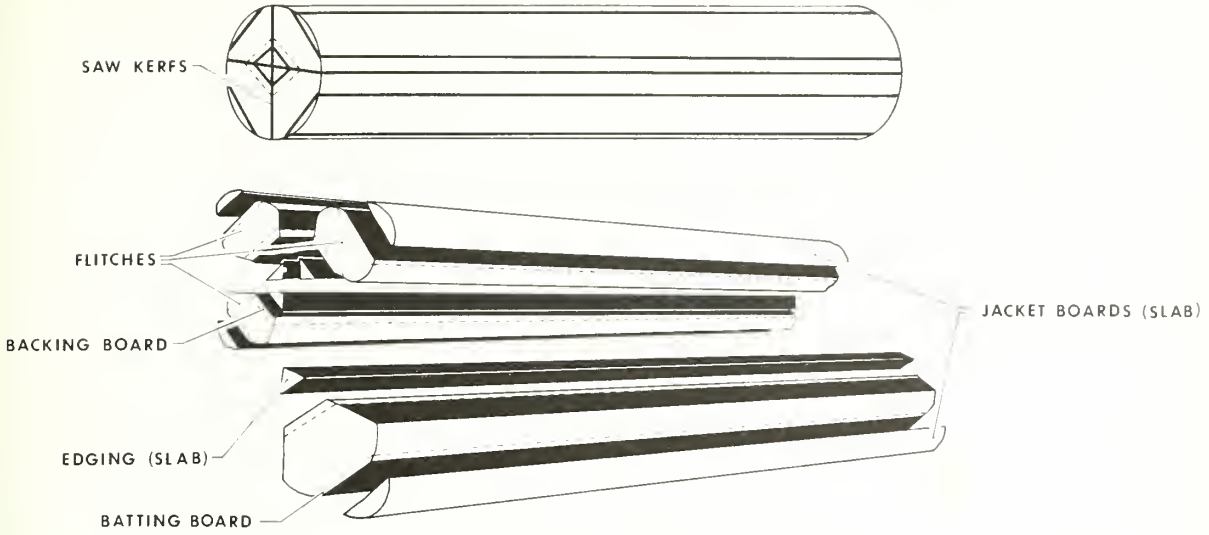


Figure 1c.—4-flitch log.



was no significant amount of volume-reducing defects for which scaling deductions had to be made.

a. Butt logs:

$$V_{B1} = 0.001818\,(3.5)\,(D_S^2 + D_S D_L + D_L^2)$$

$$V_{B2} = 0.001818\,(L - 3.5)\,(D_S^2 + D_S D_L + D_L^2)$$

b. Upper logs:

$$V_U = 0.001818(L)\,(D_S^2 + D_S D_L + D_L^2)$$

Where

V_{B1} = Cubic-foot volume of first 3.5 ft of butt log

V_{B2} = Cubic-foot volume of log length above first 3.5 ft of butt log

V_U = Cubic-foot volume of upper logs

L = Log length (1/10 ft)

D_S = Average small-end diameter of log inside the bark (1/10 in)

D_l = Average large-end diameter of log inside the bark (1/10 in)

2. Volume of batting board per log, in cubic feet.
Batting or batting boards are usable boards recovered during the process of sawing logs into flitches (see Figs. 1a-c). These were used as crating for the dried "books" of veneer. The thickness, width, and length of each board was recorded as it passed along the green chain.

3. Volume of individual flitches, in cubic feet.
Before the flitches were sliced, an outline of both ends of each flitch was traced on a sketch pad. These tracings were cut out and passed through an automatic area meter to obtain the end area in cubic centimeters. From the end area and the flitch length, the cubic volume was determined.

4. Volume of flitch end trim, in cubic feet.
By measuring the flitch before and after trimming, two different volumes for each flitch were obtained. Then end-trim volume was obtained by subtraction.

5. Volume of backing boards, in cubic feet.
The backing board or "dog" board is used to hold the flitch stationary during the slicing operation. After the flitch was sliced, the thickness, width, and length of the dog board was measured (Fig. 1a-c).

6. Volume of veneer, in cubic feet.
As the veneer came out of the dryers, each piece was graded and the width measured. Length was recorded only once for the entire flitch.

7. Volume of scrap veneer, in cubic feet.
Scrap veneer residue, which is produced at four different points in the veneering process, consists of:

a. The initial pieces of veneer sliced off the flitch until usable veneer is obtained.
b. Veneer pieces damaged during the slicing process.
c. The portion of the veneer clipped off the edges to even the books before drying.
d. Veneer ripped or torn when hung in the drying chain, and veneer with excessive buckling or curling caused by high heat.

The formula for volume was:

Scrap = Flitch − (Backing + Veneer)

8. Volume of slabs, shavings (from the flitches), and sawdust (S.S.S.), in cubic feet.

The formula for volume was:

S.S.S. = Log volume − (Batting + Flitch Ends + Flitch)

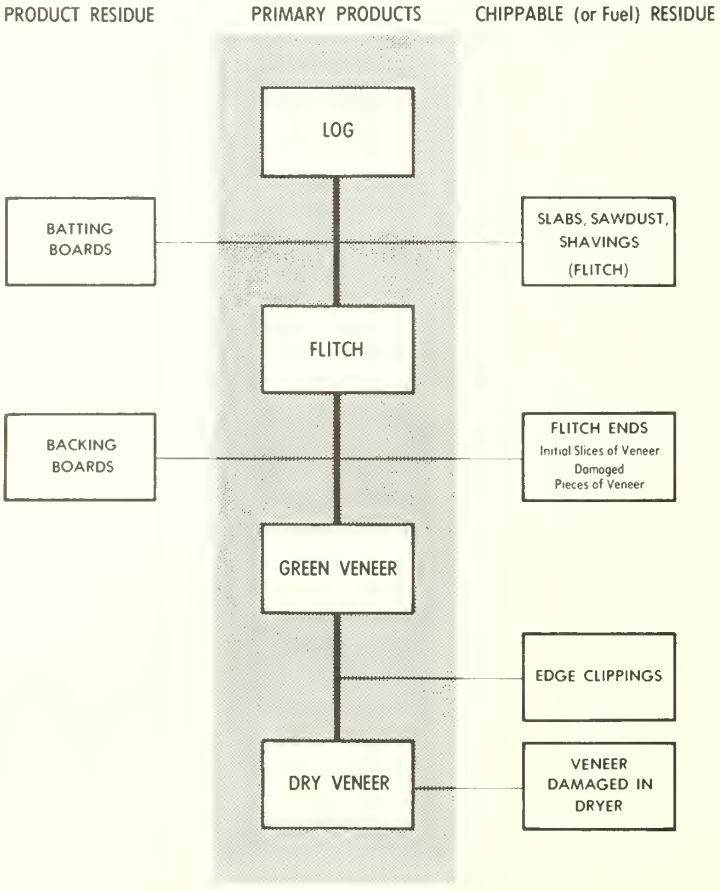
VOLUME YIELDS

The log components are grouped in three main categories (Fig. 2):

1. Primary products—log, flitch, green and dry veneer.
2. Product residue—batting and backing boards.
3. Chippable (or fuel) residue—slabs, sawdust, flitch shavings, flitch ends, initial slices of veneer, veneer damaged during slicing, edge clippings, and veneer damaged during drying.

The volume yield as a percentage of total log volume is quite different between oak and cherry for some categories. This is primarily due to the difference in the form (taper) of the butt log. Oak has considerably more butt swell than cherry. But once the flitch has been produced and the final products are compared as a percentage of flitch

Figure 2.—Breakdown of log components.



volume, there is little difference in yield between the species or within the species by these categories.

Product recovery as a percentage of total log volume

In terms of total log volume, the amount of product residue between the two species is similar. However, there is a significant difference in the amount of chippable residue produced (Figs. 3, 4). In the production of the oak flitches alone, over 25 percent of the total log volume is in chippable residue; whereas only about 20 percent of the total log volume is in this category for cherry. Continuing through the process to the final product—veneer—the percentage of chippable residue increases to 34 percent for oak and only to 29 percent for cherry. In the primary products, cherry flitch yields exceed that of oak by over 6 percent and cherry veneer yields exceed oak by over 4 1/2

Figure 3.—Black cherry log components as a percentage of total log volume.

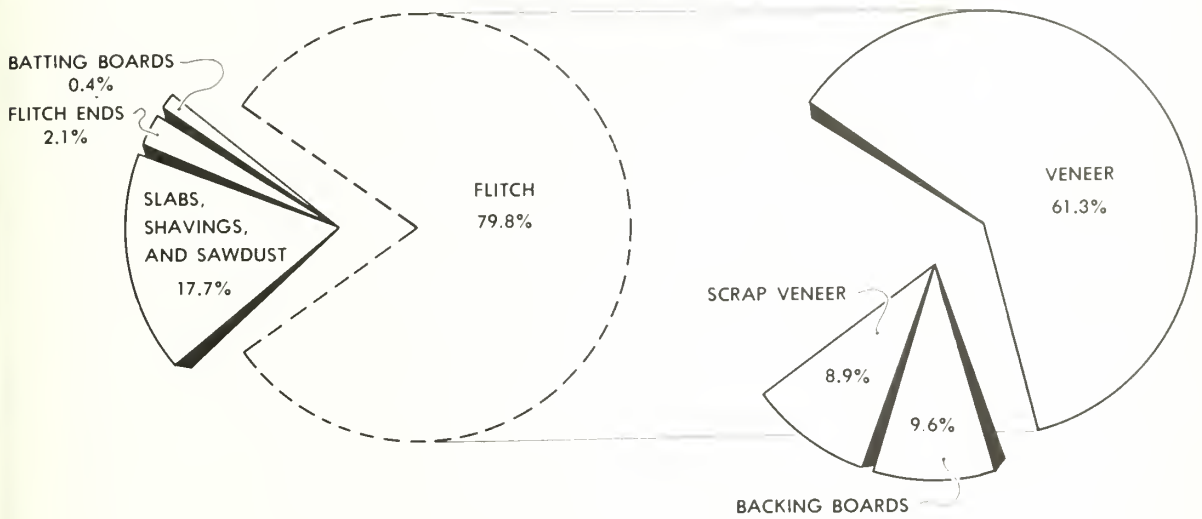
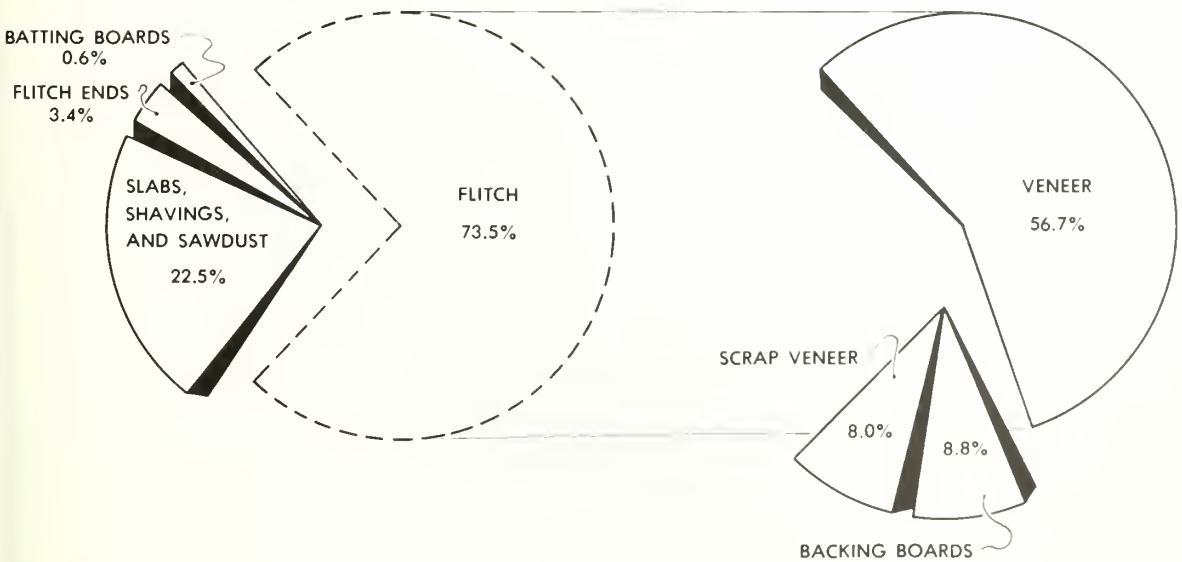


Figure 4.—Northern red oak log components as a percentage of total log volume.



percent. When the product residue is included, the total percentage of the log that is utilized, other than as fuel, is 66 percent of oak and 71 percent for cherry.

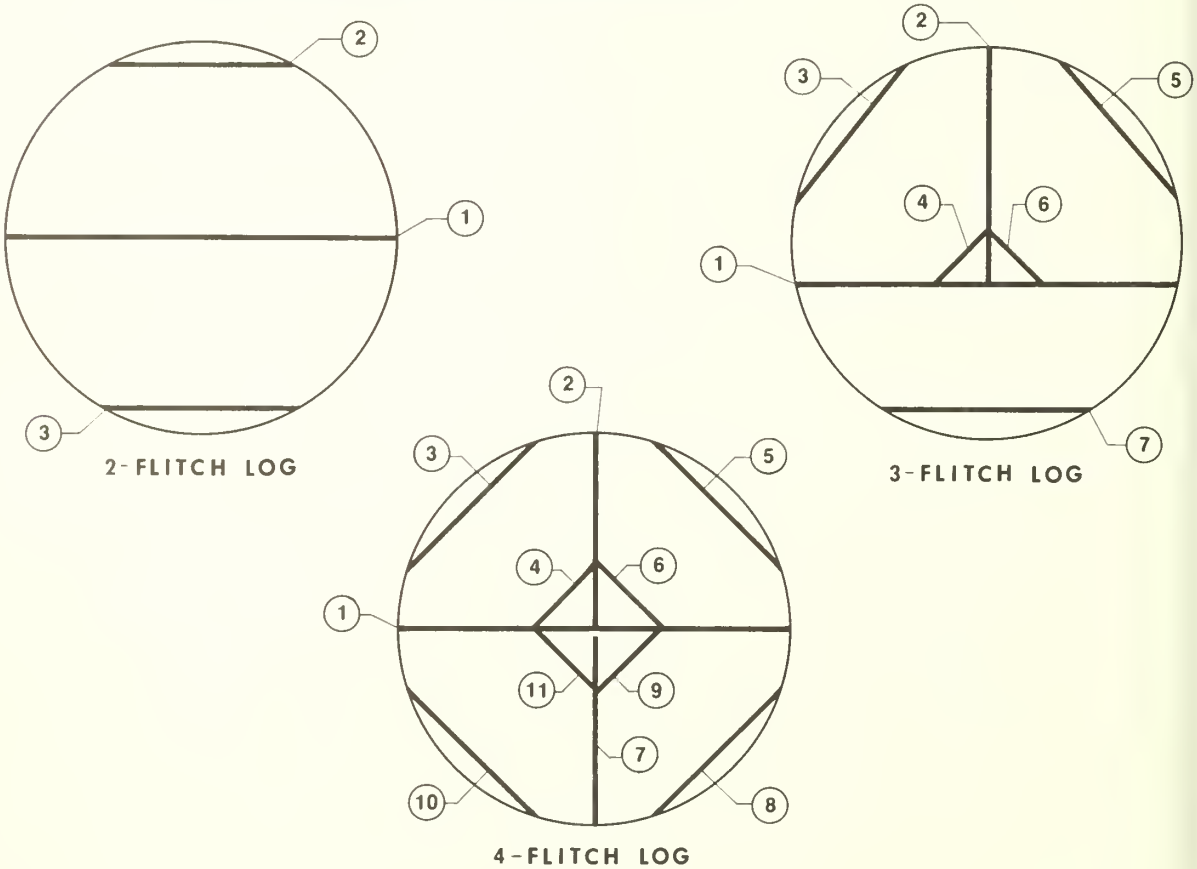
By dividing the logs of each species into groups of butt and upper logs (Table 1), it is quite obvious that the major differences between and within the species are in the butt logs. In fact, the volume percentages for the upper logs of oak and cherry are almost identical. Within the species, the difference between butt and upper logs for oak is much greater than for cherry.

The percentage of primary products plus product residue in the upper logs exceeds that of the butt logs. Two principal reasons account for this. One is that with the additional taper of the butt logs, the total log volume is increased more than the volume of the primary products and product residue. Second, butt logs contain a higher percentage of 4-flitch logs (Table 2). The percentage yield of primary product plus product residue from these logs is less than that of the 2- or 3-flitch logs (Table 3) because the percentage of batting and backing boards decreases as the number of flitches increases. One of the factors contributing to the inverse ratio between number of flitches and the percentages of primary product plus product residue is the number of saw cuts required to produce the flitches. The minimum number of saw cuts required by number of flitches (Fig. 5) is:

Flitches per log	*Saw cuts required*
2	3
3	7
4	11

Of course, if any batting boards are produced as the flitches are cut, then the number of saw cuts increases and volume is further reduced. Another factor is the change in the volume of product resi-

Figure 5.—End view of logs showing location and minimum number of cuts to produce 2, 3, or 4 flitches per log.



due among 2-, 3-, and 4-flitch logs. The backing board of the 2-flitch log is from the widest portion of the flitch whereas the backing board of the 4-flitch log is from the narrowest portion (see Figs. 1a and 1c). The volume of the 3-flitch log falls about halfway between the other two because of the location and number of cuts (Fig. 5).

From the mill owner's or manager's standpoint, the most important aspect of the breakdown by number of flitches (Table 3) is the increased yield of veneer as the number of flitches increases. This should be investigated further to determine if the cutoff points between the 2-, 3-, 4-flitch logs could be lowered to take advantage of this increase without lowering the total value of the veneer produced.

When log length is considered as a factor that affects yield, it becomes apparent that the same holds true for sawing and slicing veneer logs as for sawing logs for standard lumber—that is, as log length increases, the percentage of yield decreases (Table 4). As length increases, the taper normally increases, which results in an increase in slab volume and a decrease in the yield of the primary products. In this study, as in most log-grade studies, the butt logs tended to be longer:

Log length (feet)	*Butt logs*	*Upper logs*
8	21	61
9	10	9
10	37	31
12	12	3

Therefore, the additional taper of the butt logs compounds the taper problem, and results in a further decrease in the percentage of yield.

The breakdown by diameter cannot be adequately analyzed because there are not enough logs per diameter cell. The general trend indicates a decrease in yield of primary products as diameter increases.

Product recovery as a percentage of flitch volume

The previous data have all been based on the percentage of yield of the total log, and many differences were apparent. Now, if you consider the product yields based on flitch volume, you get a different perspective. When oak and cherry are compared (Table 5), the two are almost identical in the yield of backing boards, veneer, and scrap veneer. Also, there is little or no difference between butt and upper logs within or between species (Table 6). However, when the comparisons are made by number of flitches (Table 7), it becomes apparent that the yield of backing boards is inversely proportional and the yield of veneer is directly proportional to the number of flitches. The reason for the inverse proportion can be seen when you compare the width of the backing boards of the 2-, 3-, and 4-flitch logs (Fig. 1a-1c). The backing board comes from the widest portion of the flitch for the 2-flitch log and from the narrowest portion of the 4-flitch log. The 3- flitch log falls about halfway between because it is composed of one flitch that is a little less than one-half of the log, and each of the other two are a little larger than one-fourth of the log. Even though the volumes of both backing boards and veneer vary, the decrease in one is almost exactly offset by the increase in the other. The percentage of scrap and backing plus veneer both verify this.

Log length, according to these data, has little or no effect on the yields as a percentage of flitch volume (Table 8).

Even though the number of logs per cell is small, as previously stated, it can be seen that diameter has the same inverse relationship with backing boards and direct relationship with veneer as does the number of flitches. This is to be expected, since the number of flitches is almost perfectly correlated with diameter.

SUMMARY

The primary purpose of this study is to show the relationships between the various components that are produced when logs are processed into sliced veneer.

Since the veneer logs utilized in this study were virtually free of volume-reducing defects, the main cause of volume difference between logs of equal scaling diameter is attributed to taper. The analysis of differences between butt and upper logs support this. The comparison by species shows that form (or taper) is quite different between oak and cherry. Figures 3 and 4 give an overall view of the breakdown of components by species.

Of spécial interest to mill owners or managers is that the yield of veneer increases as the number of flitches increases (Table 3). Also, there are four stages in production that I feel should be closely examined to determine ways to reduce the loss of material that could become veneer. The percentages of residue are:

Residue	*Oak*	*Cherry*
Batting boards	0.6	0.4
Backing boards	8.8	9.6
Flitch ends	3.4	2.1
Scrap veneer	8.0	8.9
Total	20.8	21.0

These figures show that if these residue products could be reduced by 50 or even 25 percent, then this could result in a 5 to 10 percent increase in veneer volume.

ACKNOWLEDGMENTS

I acknowledge the cooperation extended by the Weyerhaeuser Co., Ridgeway, Pennsylvania, and the Forest Service personnel of the Allegheny National Forest who assisted in the field work and the milling phase of this study.

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Appendix

Table 1.—Percentage of total log volume of butt and upper veneer logs, by species, products, and residue.

Species	No. of logs	Products residue		Chippable (or fuel) residue				Primary products		Total products residue + veneer
		Batting Boards	Backing Boards	Flitch ends	Slabs, shavings, sawdust	Scrap veneer	Total fuel residue	Flitch	Veneer	
					BUTT LOGS					
Oak	39	0.4	7.9	3.9	28.4	7.0	39.3	67.3	52.4	60.7
Cherry	41	0.4	9.1	1.7	20.8	8.1	30.6	77.1	59.9	69.4
					UPPER LOGS					
Oak	47	0.9	10.0	2.7	15.4	9.2	27.3	81.0	61.8	72.7
Cherry	57	0.5	10.1	2.4	14.8	9.6	26.8	82.3	62.6	73.2

Table 2.—Percentage of flitches from butt and upper logs, by species.

Log position	2-flitch		3-flitch		4-flitch	
	No. of logs	Percent	No. of logs	Percent	No. of logs	Percent
			OAK			
Butt	11	28	5	13	23	59
Upper	10	21	13	28	24	51
			CHERRY			
Butt	9	22	6	15	26	63
Upper	15	26	10	18	32	56

Table 3.—Veneer log products and residue as a percentage of total log volume, by species and number of flitches.

No. of flitches	No. of logs	Products residue		Chippable (or fuel) residue				Primary products		Total products residue + veneer
		Batting boards	Backing boards	Flitch ends	Slabs, shavings, sawdust	Scrap veneer	Total fuel residue	Flitch	Veneer	
					OAK					
2	21	2.4	12.8	5.6	20.0	7.0	32.6	72.0	52.2	67.4
3	18	1.0	10.5	2.9	19.7	8.1	30.7	76.4	57.8	69.3
4	47	0.2	7.5	3.0	23.8	8.1	34.9	73.0	57.4	65.1
					CHERRY					
2	24	1.9	14.4	4.7	11.9	8.6	25.2	81.5	58.5	74.8
3	16	0.4	12.0	2.2	15.8	8.8	26.8	81.6	60.8	73.2
4	58	0.1	8.2	1.5	19.2	9.0	29.7	79.2	62.0	70.3

Table 4.—Veneer log products and residue as a percentage of total log volume, by species and log length.

Log length (feet)	No. of logs	Products residue		Chippable (or fuel) residue				Primary products		Total products residue + venee
		Batting boards	Backing boards	Flitch ends	Slabs, shavings, sawdust	Scrap veneer	Total fuel residue	Flitch	Veneer	
					OAK					
8	34	0.9	9.5	2.6	18.3	8.8	29.7	78.2	59.9	70.3
9	9	0.5	8.3	1.7	27.3	6.5	35.5	70.5	55.7	64.5
10	36	0.6	8.9	3.6	22.9	7.8	34.3	72.9	56.2	65.7
12	7	0.1	7.3	6.3	27.4	8.0	41.7	66.2	50.9	58.3
					CHERRY					
8	48	0.1	9.5	2.0	17.4	8.8	28.2	80.5	62.2	71.9
9	10	0.6	12.0	0.9	14.6	9.0	24.5	83.9	62.9	75.5
10	32	0.5	8.8	2.1	17.8	9.5	29.4	79.6	61.3	70.6
12	8	1.2	11.9	3.6	21.7	6.4	32.7	73.5	55.2	68.2

Table 5.—Flitch components as a percentage of total flitch volume, by species.

Species	No. of logs	Component			Backing + veneer
		Backing board	Veneer	Scrap veneer	
Oak	86	12.1	77.1	10.8	89.2
Cherry	98	12.1	76.8	11.1	88.9

Table 6.—Flitch components as a percentage of total flitch volume, by species and log position.

Log position	No. of logs	Component			Backing + veneer
		Backing boards	Veneer	Scrap veneer	
			OAK		
Butt	39	11.8	77.9	10.3	89.7
Upper	47	12.3	76.3	11.4	88.6
			CHERRY		
Butt	41	11.8	77.7	10.5	89.5
Upper	57	12.2	76.1	11.7	89.3

Table 7.—Flitch components as a percentage of total flitch volume, by species and number of flitches.

No. of flitches	No. of logs	Component			Backing + veneer
		Backing boards	Veneer	Scrap veneer	
			OAK		
2	21	17.8	72.5	9.7	90.3
3	18	13.7	75.7	10.6	89.4
4	47	10.3	78.6	11.1	88.9
			CHERRY		
2	24	17.7	71.8	10.5	89.5
3	16	14.7	74.5	10.8	89.2
4	58	10.4	78.3	11.3	88.7

Table 8.—Flitch components as a percentage of total flitch volume, by species and log length.

Log length (feet)	No. of logs	Component			Backing + veneer
		Backing boards	Veneer	Scrap veneer	
			OAK		
8	34	12.2	76.6	11.2	88.8
9	9	11.7	79.1	9.2	90.8
10	36	12.3	77.1	10.6	89.4
12	7	11.1	76.9	12.0	88.0
			CHERRY		
8	48	11.8	77.3	10.9	89.1
9	10	14.3	75.0	10.7	89.3
10	32	11.0	77.0	12.0	88.0
12	8	16.1	75.1	8.8	91.2

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THE CAUSES OF LOGGING TRUCK DELAYS ON TWO WEST VIRGINIA LOGGING OPERATIONS

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Abstract

Logging truck downtime increases timber harvesting costs. To determine the extent and causes of truck delays, four logging trucks on two separate operations were monitored for a 7-month period by recording speedometers and with tallies of delay causes.

The results show the number of truck delays per shift, their duration, and the total delay time per shift for eight categories of delay causes. Average delay time per shift was nearly 90 minutes. Maintenance and repair, administrative actions, and operations scheduling were the leading causes of truck delay; overall, they accounted for two-thirds of all delay time sampled.

LOGGING TRUCK DELAYS can increase the costs of harvesting timber. To determine how log hauling can be more efficient by reducing delay time, four logging trucks operating in West Virginia were monitored. The extent and causes of downtime were recorded.

STUDY METHODS

Four tandem-axle trucks were monitored over a period of 7 months, from March through September. The trucks were similar in age, mechanical condition, and load capacity. Each truck was equipped with a recording speedometer capable of accurately measuring and recording the operating time and delay time as well as speeds and distances driven. For this study, sample data on delays were collected from 311 truck-days (136 from Logger A, 175 from Logger B). Two trucks for each of two separate logging operations hauled from a total of eight logging sites.

Special tally sheets were printed with causes of delay listed across the top and clock time in 15-minute intervals printed along the right and left margins. When a delay occurred, the driver checked the appropriate column and row to indicate the cause of the delay and the approximate time the delay began. To ensure that the tally sheet coincided with the speedometer record, the driver used the clock on the face of the recording speedometer to determine when the delay started.

The tally sheets were used to identify the delays registered on the speedometer charts. Delay times were interpreted from the speedometer charts and the duration of each delay was recorded and tabulated by delay cause. Delays registered on the speedometer charts, and not identified on the tally sheet, were tabulated in the unexplained category.

The causes of delay were limited to eight categories:

1. *Maintenance and repair.* Truck out of service while being repaired or undergoing major preventive maintenance.
2. *Fuel — oil.* Driver refueling truck, checking oil, or performing minor servicing.
3. *Tire chains.* Truck delayed while driver mounts or removes tire chains.
4. *Lunch break.* Driver interrupts a work cycle to eat lunch or take a rest break.
5. *Truck stuck.* Truck stuck in mud or snow, or waiting for a tow.
6. *Traffic.* Truck waiting for another truck to pass on a narrow logging road, or held up by traffic.
7. *Schedule delay.* Truck delayed as a result of other factors in the operations schedule. For example, lack of logs at the landing, waiting for other trucks to load and clear the landing area, waiting for a lift truck to unload at the mill.
8. *Administrative delay.* Truck delayed because a supervisor requests the driver to perform other duties.

These were judged to be the most frequent causes of delays based on my observations. The drivers who encountered major delays that were not listed on the tally sheet generally noted the cause on the sheet. When the results were tabulated, such delays were placed in the category they best fit, or were tabulated as unexplained.

Activities such as refueling vehicles and eating lunch are everyday occurrences; however, they do not necessarily cause a production delay. If the driver eats lunch while the truck is being loaded, no delay occurs; but if he stops a loaded truck on

the way to the mill to eat lunch, there is a delay. Likewise if the truck is fueled at the beginning or at the end of the day, work is not interrupted; but if the driver interrupts a work cycle to refuel or service the truck, a delay occurs.

RESULTS

Combined results

For the two logging jobs combined, the average amount of delay time was 88.7 minutes per shift. The average number of delays was 1.2 per shift, and the average delay lasted 73.4 minutes (Table 1).

Delay frequency provides a useful means to estimate how often a specific type of delay might be expected. For example, the frequency of maintenance and repair delays was .16 per shift, or 1 delay every 6.25 shifts. Based on these results, loggers A and B could expect a maintenance and repair problem with each truck approximately every 6 working days.

The most frequent cause of delays was lunch breaks, occurring at a rate of .38 per shift and representing 31.6 percent of all delays (Tables 1 and 2). There were .24 administrative delays per shift, which accounted for 20 percent of all delays. Maintenance and repair delays ranked third, with a frequency of .16 per shift, or 13.3 percent of all recorded delays.

The average duration of delays varied a great deal among causes. Of all identified delays, those caused by maintenance and repair were longest, and they averaged 157.8 minutes. Two other sources of long delays were scheduling delay (average 153.8 minutes) and administrative delay (average 101.5 minutes).

At the low end of the scale, delays caused by refueling averaged only 10.7 minutes; traffic delays averaged 11.0 minutes (Table 1).

Perhaps the most important measurement of delay is the average total delay time per shift, which indicates the amount of productive time lost each day. Maintenance and repair accounted for the highest total delay time with 25.4 minutes per shift, or 28.6 percent of all delay time sampled. Administrative activities were another major source of delay, averaging 24.5 minutes per shift and representing 27.6 percent of all delay time. Maintenance and repair, administrative activities, and operations scheduling were responsible for two-thirds of all delay time sampled.

Driving and road conditions, which are represented by traffic, mounting or removing tire chains, and trucks that are stuck, caused an average of only 6.0 minutes of delay per shift, or 6.7 percent of the total delay time. These figures are surprisingly low since all four trucks negotiated temporary logging roads at nearly every site.

Operator comparisons

There were several differences in the delay time sampled on the two logging operations. Most important, Logger B averaged 115.5 minutes of delay per shift as compared to 54.3 minutes per shift for Logger A. Both the number and the duration of delays were greater for Logger B than for Logger A (Table 1).

For all delays except those caused by refueling and scheduling, the average delay time per shift for Logger B exceeded that for Logger A. Although the frequency of maintenance and repair delays was higher for Logger A, .21 versus .11, the average time per delay was 91.9 minutes for Logger A as compared to 265.5 for Logger B. As a result, maintenance and repair delays averaged 29.3 minutes per shift for Logger B and 20.3 for Logger A.

DISCUSSION

The average delay time per shift sampled was 88.7 minutes for the combined operations, and nearly 2 hours for one of the loggers. These results show that truck downtime can be a problem that loggers should be concerned with. Losing as much as 2 hours of truck production time per shift can significantly increase logging costs.

The differences between loggers or between causes of delay could not be explained with the data that were collected. Maintenance, management, and operating conditions were not evaluated on each logging job. Nonetheless, the fact that the leading causes of truck delay were management related, and that large differences were found between the two operators sampled, suggests that managers could control truck delay time.

Logging roads did not appear to be much of a problem for the operations studied. Delays caused by driving and road conditions (truck stuck, tire chain, traffic) contributed very little to total delay

Table 1. Number and duration of truck delays and total truck delay time per shift, by cause of delay

Cause of delay	Delays per shift			Average duration of delay[a]			Average total time/shift		
	Logger A	Logger B	Both[b]	Logger A	Logger B	Both[c]	Logger A	Logger B	Both[b]
	-Number-			-Minutes-					
Maintenance and repair	0.21	0.11	0.16	91.9	256.5	157.8	20.3	29.3	25.4
Fuel-oil service	.26	.02	.13	10.4	13.8	10.7	2.7	0.3	1.3
Tire chains	.01	.01	.01	5.0	70.0	48.3	.04	.8	.46
Lunch break	.19	.53	.38	20.1	28.6	26.7	3.8	15.2	10.2
Truck stuck	.13	.06	.09	29.8	86.4	51.3	3.9	5.4	4.8
Traffic	.07	.06	.07	9.9	12.0	11.0	.73	.75	.74
Administrative	.05	.39	.24	90.4	102.7	101.5	4.65	39.9	24.5
Scheduling	.07	.05	.06	274.0	33.7	153.8	18.1	1.7	8.9
Unexplained	—	.13	.07	—	175.3	175.3	—	22.0	12.4
All delays	1.0	1.37	1.21	54.3	84.2	73.4	54.3	115.4	88.7

[a] Columns not additive because delay causes occurred at different frequencies.
[b] An average weighted by the number of shifts sampled per logger.
[c] An average weighted by the number of delays sampled per logger.

Table 2. Percentage of total number of truck delays and of total delay time, by cause of delay

Cause of delay	Number of delays			Delay time		
	Logger A	Logger B	Both[a]	Logger A	Logger B	Both[b]
Maintenance and repair	22.1	8.3	13.3	37.3	25.4	28.6
Fuel-oil service	25.7	1.7	10.4	4.9	.3	1.5
Tire chains	.7	.8	.8	.1	.7	.5
Lunch	19.1	38.7	31.6	7.1	13.1	11.5
Truck stuck	13.2	4.6	7.7	7.3	4.7	5.4
Traffic	7.4	4.6	5.6	1.3	.6	.8
Administrative	5.2	28.3	20.0	8.6	34.6	27.6
Scheduling	6.6	3.8	4.8	33.4	1.5	10.1
Unexplained	—	9.2	5.8	—	19.1	14.0
Total	100.0	100.0	100.0	100.0	100.0	100.0

[a] An average weighted by the total number of delays per logger.
[b] An average weighted by the total delay time per logger.

time. If sampling had continued into the winter months, these delays would probably have increased.

The results indicate that efficient trucking requires special attention to maintenance and repair, administrative actions, and the scheduling of harvesting operations. Downtime can be reduced by preventive maintenance and by balancing the logging and hauling phases of the operation.

This study has also shown that recording speedometers and drivers' tally sheets can provide a relatively accurate and economical means of collecting data on truck delays. This method can also be used to monitor other types of logging machines so that a manager can determined how to improve operations.

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Abstract

Two sample plots in poletimber-small sawtimber stands of Allegheny hardwoods were thinned to improve crop-tree spacing. Thinning produced nearly 35 tons per acre of wood fiber, including 13 tons of sawable boltwood, 3-1/2 tons of standard sawlogs, 18 tons of pulpwood, and 1 ton of fuelwood. Nearly 3,700 board feet of lumber and cants were produced from the sawbolts and sawlogs. An additional 34 tons suitable for wood chips or fuelwood or both were available but not harvested.

INTRODUCTION

A RECENT STUDY of forest management needs in the Northeast showed that more than one-half of the 42 million acres in the oak-hickory and beech-birch-maple types needed thinning or improvement cutting. In the Appalachian Region, a similar portion of timberland consists of overstocked poletimber-small sawtimber stands. For example, of 700,000 acres of timberland on the Monongahela National Forest, more than 300,000 acres need thinning. These stands are in the 40- to 60-year age class and most are located on the better sites. The dominant and codominate trees in these stands range from 6 to 14 inches in diameter at breast height (dbh); but due to overstocking, the stands are becoming stagnant, and there is a high rate of mortality. Timber managers on the Monongahela National Forest estimate that 200,000 cords of wood are lost annually.

Large-scale commercial thinning is limited because traditional logging and sawmill systems are desgined for harvesting and processing the larger, higher grade timber; small trees cannot be used efficiently. New or modified systems will be required for commercial harvesting from thinnings. To develop such systems, information is needed on the types and quantity of products that can be recovered from the small trees removed in thinnings.

STUDY AREA

We selected two sample plots on the Middle Mountain section of the Monongahela National Forest near Elkins, West Virginia. They represent approximately 100,000 acres of overstocked poletimber-small sawtimber stands of Allegheny hardwoods on Middle Mountain.

The first plot contains 5.9 acres and is located on a ridgetop at an elevation of 3,700 feet. The site index for black cherry is 80. Initial stocking was 147.9 square feet (ft^2) of basal area per acre, of which 8.9 ft^2 was in saplings, 65.7 ft^2 was in poletimber, and 73.3 ft^2 was in sawtimber. The initial distribution of basal area among species was: black cherry (*Prunus serotina* Ehrh.), 45.6 ft^2; sugar maple (*Acer saccharum* Marsh.), 40.0 ft^2; white ash (*Fraxinus americana* L.), 26.7 ft^2; red maple (*Acer rubrum* L.), 18.9 ft^2; beech (*Fagus grandifolia* Ehrh.), 6.7 ft^2; cucumbertree (*Magnolia accuminata* L.), 5.6 ft^2; other 4.4 ft^2.

The second plot contains 5.6 acres, and is located at an elevation of 3,400 feet. The site index is 90 for black cherry. Initial stocking was 151.2 ft^2 of basal area per acre, of which 12.5 ft^2 was in saplings, 53.7 ft^2 was in poletimber, and 85.0 ft^2 was in sawtimber. The distribution of basal area among species was: black cherry, 62.5 ft^2; red maple, 32.5 ft^2; cucumbertree, 32.5 ft^2; black birch (*Betula lenta* L.), 15.0 ft^2; white ash, 2.5 ft^2; (Tables 1 and 2).

Table 1.—Stocking by species for two study plots on Middle Mountain section of Monongahela National Forest

Species	Basal area			Number of trees/acre			Mean dbh (inches)		
	Initial	Designated removal	Residual	Initial	Designated removal	Residual	Initial	Designated removal	Residual
					PLOT 1				
Sugar maple	40.0	26.6	13.4	230	192	38	5.6	4.9	8.0
Red maple	18.9	11.1	7.8	90	72	18	6.2	5.3	8.9
Black cherry	45.6	13.3	32.3	62	31	31	11.6	8.9	13.8
Ash	26.7	10.0	16.7	62	31	31	8.9	7.7	9.9
Beech	6.7	3.4	3.3	19	10	9	8.0	7.8	8.2
Magnolia spp.	5.6	3.3	2.3	9	6	3	10.7	10.0	11.6
Miscellaneous	4.4	3.3	1.1	45	42	3	4.2	3.8	8.2
All species	147.9	71.0	76.9	517	384	133	7.2	5.8	10.3
					PLOT 2				
Sugar maple	6.2	5.0	1.2	44	40	4	5.1	4.8	7.4
Red maple	32.5	23.8	8.7	234	213	21	5.0	4.5	8.7
Black cherry	62.5	16.2	46.3	81	26	55	11.9	10.7	12.4
Ash	2.5	.0	2.5	4	0	4	10.7	—	10.7
Black birch	15.0	15.0	.0	44	44	0	7.9	7.9	—
Magnolia spp.	32.5	15.0	17.5	74	47	27	9.0	7.6	10.9
All species	151.2	75.0	76.2	481	370	111	7.6	6.1	11.3

Table 2.—Stocking by tree size class for two study plots

Item	Basal area (ft^2/acre)			Number of trees/acre		
	Initial	Designated cut	Residual	Initial	Designated cut	Residual
			PLOT 1			
Saplings	8.9	8.9	0	149	149	0
Poletimber	65.7	43.2	22.5	281	208	72
Sawtimber	73.3	18.9	54.4	87	27	61
Total	149.9	71.0	76.9	517	384	133
			PLOT 2			
Saplings	12.5	12.5	0	166	166	0
Poletimber	53.7	41.2	12.5	201	170	31
Sawtimber	85.0	21.2	63.7	114	34	80
Total	151.2	75.0	76.2	481	370	111

PROCEDURE

The residual crop trees were marked to provide the desired crop-tree spacing and stand density. The marking designated a residual stocking of 76.9 ft^2/acre on Plot 1 and 76.2 ft^2/acre on Plot 2.

The thinning on Plot 1 favored the faster growing, less tolerant, and more valuable cherry and ash. Thinning on Plot 2 eliminated the low-value, disease-prone birch, favoring the cherry and cucumbertree, which were dominant or codominate.

All trees designated for removal that were 5.5 inches in dbh or larger were felled, topped to a 4-inch minimum diameter inside bark (dib), and skidded, tree length, to a central landing for each plot.

Each stem was bucked into the longest straight or nearly straight pieces from 4 to 16 feet long as follows: **sawlogs:** pieces at least 8 inches in diameter by 8 feet long that would meet the U.S. Forest Service grade requirements for standard sawlogs (Rast et al. 1973); **sawbolts:** pieces at least 6 inches in diameter by 4 feet long, and straight enough to yield at least one sound square-edge 4- by 4-inch cant (National Hardwood Lumber Association 1974); **pulpwood:** pieces 4 to 5.6 inches in diameter by 5 feet long, and larger diameter pieces that were not straight or sound enough to yield a sawbolt; **firewood:** pieces too short for pulpwood or sawbolts.

Sawbolts were further divided as follows: **furniture round bolts:** pieces 4 feet long by 7.5 inches or larger in diameter and free of unsound defects; **pallet bolts:** all other 4-foot sawbolts; **furniture dimension bolts:** sound 6-foot-long bolts 7.5 inches or larger in diameter; **sawmill bolts:** all bolts 5 to 8 feet long exclusive of the furniture dimension bolts; **poles:** pieces 8 feet long or longer but less than 8 inches in diameter.

Sawlogs, sawbolts, pulpwood, and firewood were weighed and tallied separately. Cubic-foot volume and board-foot content were determined for each sawlog and sawbolt. All sawlogs and sawbolts were converted into the appropriate primary products for existing markets. Pulpwood and firewood were delivered to local markets.

YIELDS

Of the 71 ft^2/acre of basal area available for removal on Plot 1, 51 ft^2 were removed. Of the 75 ft^2/acre of basal area available on Plot 2, 55 ft^2 were removed. The remaining basal area on both the plots was in trees less than 5.5 inches in dbh; these trees did not meet current merchantability standards.

Biomass

The green weight of the above-ground portion of various stand components was estimated using whole-tree weight equations developed by Wartluft (1977). The results indicated that there were 69.2 tons of wood fiber available from each acre thinned; included were 17.9 tons of roundwood pulpwood, 16.5 tons of sawable logs and bolts, and 34.8 tons of fiber such as whole-tree chips or fuel-wood (Tables 3 and 4).

The available biomass that was not removed

Table 3.—Roundwood yields for two study plots, in board feet, cubic feet, and tons per acre

Item	Plot 1			Plot 2			Average		
	Weight (tons)	Volume		Weight (tons)	Volume		Weight (tons)	Volume	
		fbm[a]	ft³		fbm[a]	ft³		fbm[a]	ft³
Firewood	1.1	—	39.6	1.5	—	49.5	1.3	—	44.4
Pulpwood	15.4	—	572.5	20.6	—	686.7	17.9	—	628.1
Pallet bolts	6.1	804	201.9	5.9	857	187.1	6.0	830	194.7
Furniture round bolts	.4	97	16.4	.9	193	35.3	.6	144	25.6
Furniture dimension bolts	1.0	195	37.8	.8	141	26.2	.9	169	32.2
5- to 8-foot bolts	5.5	890	204.3	3.4	605	128.1	4.5	751	167.2
Poles	.8	120	30.1	1.0	170	37.3	1.0	144	33.6
Grade 2 sawlogs	.5	96	16.6	.6	131	20.4	.5	113	18.5
Grade 3 sawlogs	2.0	423	75.7	4.2	861	157.9	3.0	636	115.7
Total	32.8	2,625	1,194.9	38.9	2,958	1,328.5	35.7	2,787	1,260.0

[a] International 1/4-inch log scale.

Table 4.—Above ground green weight of individual stand components, tons per acre

Stand component	Plot 1	Plot 2	Average
Initial stand	153.3	158.8	156.0
Designated residual trees	86.4	87.1	86.7
Trees available for removal	66.9	71.7	69.2
Products actually removed	32.8	38.9	35.7
Remaining available biomass; trees <5.5 inches in dbh and residue from cut trees	34.1	32.8	33.5
Remaining material available for removal in pieces >3.0 inches in dob	18.0	16.4	17.2

consisted of trees less than 5.5 inches in dbh that were not harvested, and the tops and limbs of trees that were cut. We estimated that the remaining available biomass in pieces larger than 3 inches in diameter outside bark (dob) made up approximately 17 tons per acre. This material is suitable for solid fuelwood (Table 4).

Roundwood

The average combined per acre yield for the two plots was:

Item	*Tons*	*Cubic feet*
Pulpwood	17.9	628.1
Sawbolts (4 feet)	6.6	220.3
Sawbolts (5 to 8 feet)	5.4	199.4
Sawlogs and poles	4.5	167.8
Firewood	1.3	44.4
Total	35.7	1,260.0

See Table 3 for individual plot yields and subclassifications.

Bolts that were 4 feet long accounted for 41.3 percent of the sawable volume from Plot 1 and 37.5 percent on Plot 2. Nearly 90 percent of the bolt and log volume on both plots was in pieces with a scaling diameter of 10 inches or less (Table 5).

Sawed products

The yield of sawable wood averaged 2,787 board feet per acre (International 1/4-inch log scale), from which 3,695 board feet of sawn products was produced as follows: 1,344 board feet of pallet parts and 76 board feet of furniture rounds from the 4-foot bolts; 1,216 board feet of cants and lumber from the 4- to 8-foot sawmill bolts; and 1,059 board feet of cants and lumber from

Table 5.—Distribution of sawable cubic foot volume by diameter and length class, in percent

Length (feet)	Diameter (inches)													Total
	6	7	8	9	10	11	12	13	14	15	16	17	18	
						PLOT 1								
4	13.9	12.8	6.8	4.4	2.4	0.9	—	0.1	—	—	—	—	—	41.3
5	5.1	3.1	2.9	.8	1.2	—	.6	.3	—	—	—	.3	—	14.3
6	3.1	3.6	4.6	3.3	1.8	1.1	1.2	—	—	—	—	—	.4	19.0
7	1.0	1.3	1.0	.7	.3	—	.3	—	.3	—	—	—	—	4.9
8	2.2	2.7	3.5	2.1	2.5	1.7	.5	.3	1.5	1.0	—	1.4	1.0	20.5
Total	25.4	23.5	18.8	11.3	8.2	3.7	2.6	0.7	1.8	1.0	0.0	1.7	1.4	100.0
						PLOT 2								
4	5.3	10.6	9.1	6.2	4.4	1.4	.3	.1	.1	—	—	—	—	37.5
6	5.0	7.5	5.6	4.1	2.4	1.3	.2	.2	—	—	—	—	—	26.3
8	1.9	4.2	5.5	7.7	3.9	2.9	.4	—	—	—	—	—	—	26.5
10	.1	.8	.4	.5	.9	.6	.3	—	—	—	—	—	—	3.6
12	.5	1.1	1.1	1.1	.5	—	—	—	—	.5	0.6	—	.7	6.1
Total	12.8	24.2	21.7	19.6	12.1	6.2	1.2	0.3	0.1	0.5	0.6	0.0	0.7	100.0

Table 6.—Sawn-product yields, in board feet per acre

Item	Plot 1		Plot 2		Average	
	Input[a]	Yield[b]	Input[a]	Yield[b]	Input[a]	Yield[b]
Pallet bolts	804	1,402	857	1,284	830	1,344
Furniture round bolts	97	43	193	110	144	76
4- to 8-foot sawbolts	890	1,217	605	782	751	1,005
Furniture dimension bolts	195	249	141	172	169	211
Poles	120	181	170	211	144	196
Sawlogs	519	562	992	1,180	749	863
Total	2,625	3,654	2,957	3,739	2,787	3,695

[a] International 1/4-inch log scale.
[b] Lumber scale.

poles and sawlogs. Individual plot yields are given in Table 6.

Sawable yields and tree species

On both plots, most of the trees available for removal were red or sugar maple. However, the small average diameter of the maples on these plots limited the yield of sawable products. Few cherry and cucumbertrees were cut, but these species produced relatively high yields of sawable products because of their size. On Plot 1, black cherry yielded 30 percent of the sawable volume from 8 percent of the trees cut. On Plot 2, cucumbertree and cherry provided 73.8 percent of the sawable volume from 19.7 percent of the trees cut (Table 7).

Differences in diameter, sweep , and crook also affected the length of sawable pieces harvested from various tree species. Cucumbertree and sugar maple produced the lowest proportion of 4- and 5-foot bolts (13.2 percent and 32.4 percent of the sawable volumes, respectively). Ash and beech had the highest proportion of short pieces; more

Table 7.—Proportion of cubic foot volume in sawable logs and bolts, by species

Tree species	Plot 1	Plot 2	Plots 1 and 2 combined
		-Percent-	
Black cherry	30.0	54.7	40.0
Red maple	26.9	9.0	16.7
Sugar maple	26.0	4.6	20.5
Cucumber-tree	2.5	19.1	10.2
Magnolia	.6	2.3	1.4
Beech	7.7	—	3.5
Black birch	.7	9.0	4.6
White ash	5.0	1.3	2.9
Miscellaneous	.6	—	.2

Table 8.—Values per acre for roundwood products delivered to the nearest markets

Item	Amount	Value per unit	Total value
	PLOT 1	*-Dollars-*	
Firewood	0.4 cords	75.00	30.00
Pulpwood	15.4 tons	8.75	134.75
Pallet bolts	2.5 cords	35.00	87.50
Furniture rounds	0.060 M fbm Doyle	250.00	15.00
4- to 8-foot sawbolts	0.476 M fbm Doyle	50.00	23.80
Poles	0.042 M fbm Doyle	40.00	1.66
Grade 3 sawlogs	0.271 M fbm Doyle	50.00	13.55
Grade 2 sawlogs	0.076 M fbm Doyle	75.00	5.70
			311.96[a]
	PLOT 2		
Firewood	0.6 cords	75.00[c]	45.00
Pulpwood	20.6 tons	8.75	180.25
Pallet bolts	2.5 cords	35.00	87.50
Furniture rounds	0.128 M fbm Doyle	250.00	32.00
4- to 8-foot sawbolts	0.344 M fbm Doyle	50.00	17.20
Poles	0.068 M fbm Doyle	40.00	2.72
Grade 3 sawlogs	0.494 M fbm Doyle	50.00	24.70
Grade 2 sawlogs	0.097 M fbm Doyle	75.00	7.28
			396.65[b]

[a] Additional 34.1 tons fiber available @ $10/ton = $341.00/acre.

[b] Additional 32.8 tons fiber available @ $10/ton = $328.00/acre.

[c] Limited market available at this value ($25.00 per face cord for 16 inch wood).

than 75 percent of the sawable volume was in 4- and 5-foot bolts. Cucumbertree and black cherry yielded the highest proportion of sawable volume in bolts and logs 8 feet long or longer (61.4 percent and 31 percent, respectively).

VALUES

The product values represent the gross value of various products delivered as raw material to wood processors (Table 8). These values provide a realistic estimate of the value of the products actually obtained from the two thinned plots. The total value does not necessarily represent the maximum value that could have been obtained, because the stems were bucked into the longest straight or nearly straight pieces without regard for product value. For example, the Grade 3 sawlogs valued at $50 per thousand board feet would have been more valuable had they been bucked into 4-foot pallet bolts at $35 per cord, the equivalent of $70 per thousand board feet.

To harvest thinning material on a commercial basis, the delivered value of products must be more than the cost of logging and transportation. Although thinning cost data are limited, a recent study estimated the cost of producing whole-tree chips and sawlogs from thinnings in northern hardwood poletimber stands (Biltonen et al. 1976). Stands were thinned with a feller-buncher and a grapple skidder. Sawlogs were bucked out and the remaining material was chipped on the site with a whole-tree chipper; the total cost of logging, chipping, and transportation was $8.78 per ton. To buck out and sort a variety of products would require an extra chain saw operator as well as a small forklift to sort and pile bolts and logs. These additions would boost the cost per ton to approximately $9.50.

The average value of products obtained from the two plots was $9.85 per ton. If all available biomass, with the exception of the sawable logs and bolts, had been processed into whole-tree chips $10 per ton, the average value of products would equal $10.65 per ton. This amount exceeds the estimated cost of logging and transportation.

UTILIZATION

Because of current wood markets and prices, opportunities for commercial utilization of thinnings will depend primarily on the proportion of thinned wood that will yield products with higher values than pulpwood or chips. Although thinnings from the study plots yielded only 749 board feet per acre of sawlogs, the total yield of sawable wood averaged 2,787 board feet per acre (International 1/4-inch log scale). This figure represents 16.5 tons or 46.2 percent of the gross tonnage of wood removed.

Except for bolts suitable for furniture rounds (which comprised only 2.8 percent of sawable wood weight), the value per ton for pallet bolts exceeded that for all other roundwood products. So it seems that the opportunity to use thinnings from Middle Mountain would require the trees to be converted into two roundwood products: pulpwood and pallet bolts (except for a small percentage of pieces larger than 12 inches small end diameters). The approximate average value of roundwood would be $11.39 per ton or $406.96 per acre. Broken down by product, the average values would be:

Product	*Value per ton*	*Tons per acre*	*Value per acre*
Pulpwood	$ 8.75	17.9	$156.62
Pallet bolts	14.58	16.0	233.28
Other	9.48	1.8	17.06

CONCLUSION

Thinning two overstocked poletimber-small sawtimber stands of Allegheny hardwoods yielded nearly 3,700 board feet of sawn products, and more than 19 tons of pulpwood and fiber per acre. However, most of this material was derived from small logs and trees. Less than 25 percent of the sawn products came from sawlogs; most of it was produced from bolts 8 inches or less in diameter, and 6 feet or less in length.

If 5,000 acres of Middle Mountain poletimber stands were thinned each year over the next 10 years, 895,000 tons of pulpwood and approxi-

mately 140 million board feet (International 1/4-inch scale) of pallet bolts would be available from thinnings 5.5 inches in dbh or larger. An additional 1,705,000 tons of whole-tree chips could be manufactured from thinned trees less than 5.5 inches in dbh, and tops from trees greater than 5.5 inches in dbh.

We are now determining potential product yields from thinnings in northern hardwood, oak-hickory, and yellow-poplar stands to predict product potential (for a variety of products) for thinning the major timber types in the region.

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LUMBER GRADE YIELDS FOR GRADED ASPEN LOGS AND TREES

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Abstract

Green lumber grade yields for aspen were determined for use with the U.S. Forest Service hardwood log and tree grades. The yields for logs are expressed in percent of total lumber tally volume, and those for trees are expressed in board feet. Overruns for the International 1/4-inch and Scribner log rules along with lumber recovery factors are shown by log grade.

INTRODUCTION

U.S. FOREST SERVICE standard log and tree grades for all Eastern hardwoods are available (Hanks 1976, Rast and others 1973). Lumber grade yields to accompany the log and tree grades have been published for many species (Hanks 1965, Hanks 1976, Schroeder and Hanks 1967, Vaughan and others 1966). Aspen has been one exception.

Aspen, while not commonly thought of as a major hardwood lumber species, has received increased interest in the lumber market. To consider all aspen logs as pulpwood is unwise, for a significant volume of graded aspen lumber is being produced and sold.

For this study, we determined green lumber grade yields for graded aspen logs and trees. Part I presents yield and overrun information for the logs, and Part II, yields for the trees. By applying current lumber prices to these yields, you can estimate the value of lumber in a log or tree. Then, after the appropriate costs are subtracted, you can predict value at either the stump or at the mill.

PART I — ASPEN LOGS

Data collection

More than 600 aspen logs were available for Part I of this study. About two-thirds of these logs were bucked from the sample trees used for Part II of this paper. The remaining one-third were from mill analyses conducted by the State and Private branch of the U.S. Forest Service in cooperation with the state of Minnesota. The logs which were sawn at three band sawmills, were representative of a variety of geographic locations.

Each log was graded according to the U.S. Forest Service Standard Grades for Hardwood Factory Lumber Logs. Specifications for the log grades may be found in the Appendix. The gross board-foot scale, by both the International 1/4-inch and Scribner log rules, and the defect percentage were obtained for each log; the defect percentage was converted into board feet, and the net scale by both log rules was calculated for each log. The green lumber from each log was graded by a National Hardwood Lumber Association certified inspector. Thickness, surface measure, and grade were recorded for each board. Gross cubic-foot log volumes were computed by Smalian's equation:

$$\text{cubic-foot volume} = \left(\frac{B_1 + B_2}{2} \right) L$$

where

B_1 = area of large end, inside bark
B_2 = area of small end, inside bark
L = log length

Results

Board-foot volume by lumber grade was summed for each log-grade diameter class. These volumes formed the base for the percentage distributions in Table 1 which represent the actual green lumber grade yields. We have also provided curved lumber grade yields (Table 2). Yields for each combination of log grade and lumber grade were developed by solving regression equations in which dib (scaling diameter) and $(dib)^2$ were the independent variables (Table 3). For the 13-inch class, we have demonstrated the effect of log grade on lumber grade yield (Fig. 1). The predicted yield of No. 1C and Better lumber for grades 1, 2, and 3 was 60, 40, and 25 percent, respectively.

The lumber thickness distribution that resulted from sawing the study logs is presented in Table 4. Note that over 95 percent of the volume was sawed into 4/4-inch lumber.

Overrun percentages[1] for both the International 1/4-inch and Scribner log rules are shown in Table 5 along with cubic-foot volumes and lumber recovery factors.

Overrun averaged 4.5 percent for the International 1/4-inch rule and 24.0 percent for the Scribner log rule. For these logs, overrun was related to log grade; and within each log grade, overrun decreased as log size increased. Lumber recovery factor (LRF) represents board feet of lumber sawn per gross cubic foot of log volume. The overall average LRF was 6.12. As expected, both log grade and log size affected the LRF.

[1] $\text{Overrun (percent)} = \dfrac{\text{lumber tally} - \text{net scale} \times 100}{\text{net scale}}$

Table 1.—Actual green lumber grade yields for aspen sawlogs,[a] in percent

Scaling diameter (inches)	Number of logs	Total green lumber tally (fbm)	Lumber grade				
			FAS	SEL	No. 1C	No. 2C	No. 3C
			LOG GRADE 1				
13	42	4,715	9.3	16.8	31.1	37.1	5.7
14	23	3,266	15.8	23.5	28.9	24.6	7.2
15	13	2,058	23.6	20.5	27.9	23.7	4.3
16	10	1,573	15.9	19.8	33.3	25.3	5.7
17	1	221	5.0	43.9	22.6	28.5	.0
18	1	240	33.3	26.7	14.2	25.8	.0
			Total Lumber Tally, Board Feet				
	90	12,073	1,783	2,451	3,594	3,564	681
			LOG GRADE 2				
10	18	1,086	3.6	16.5	22.5	45.4	12.0
11	53	3,628	2.3	10.4	23.1	43.4	20.8
12	74	6,130	3.3	10.3	24.4	48.5	13.5
13	41	3,877	3.8	10.0	24.1	38.2	23.9
14	22	2,182	6.2	14.5	29.8	36.4	13.1
15	14	1,700	4.3	15.7	28.8	37.0	14.2
16	5	686	8.7	10.1	24.9	36.3	20.0
17	1	125	.0	7.2	31.2	34.4	27.2
			Total Lumber Tally, Board Feet				
	228	19,414	739	2,234	4,863	8,241	3,337
			LOG GRADE 3				
8	40	821	0.0	0.0	2.3	46.8	50.9
9	48	1,352	.0	.7	2.0	57.7	39.6
10	89	3,961	.6	4.0	11.4	48.5	35.5
11	44	2,353	.2	3.1	11.4	40.0	45.3
12	36	2,601	.3	2.2	23.9	33.7	39.9
13	23	1,973	1.4	3.5	16.4	50.2	28.5
14	5	423	.0	.0	26.0	42.8	31.2
15	3	296	2.0	2.7	20.3	55.1	19.9
16	3	399	3.5	6.0	27.8	41.1	21.6
			Total Lumber Tally, Board Feet				
	291	14,179	86	399	1,990	6,402	5,302

[a] National Hardwood Lumber Association rules for the measurement and inspection of hardwood and cypress lumber. (Published biennially by National Hardwood Lumber Association, Chicago, Illinois.)

Table 2.—Curved green lumber grade yields for aspen sawlogs, in percent

Scaling diameter (inches)	Lumber grade				
	FAS	SEL	No. 1C	No. 2C	No. 3C
			LOG GRADE 1		
13	11	18	31	34	6
14	14	20	30	30	6
15	17	22	30	26	5
16	21	24	28	22	5
17	24	26	28	18	4
18	28	28	27	14	3
			LOG GRADE 2		
10	3	13	22	46	16
11	3	12	23	45	17
12	3	11	24	44	18
13	4	11	25	42	18
14	5	11	27	39	18
15	6	13	28	36	17
16	7	16	29	32	16
17	8	19	30	28	15
			LOG GRADE 3		
8	0	0	0	54	46
9	0	2	5	50	43
10	0	3	10	47	40
11	1	3	14	44	38
12	1	3	18	43	35
13	1	3	21	42	33
14	2	3	23	42	30
15	2	2	25	43	28
16	2	2	26	45	25

Table 3.—Regression equations, mean lumber volumes, standard error of the estimates, and correlation coefficients for aspen log grades

Dependent variable: lumber grade	Independent variables			Mean lumber volume (percent)	Standard error of the estimate	Multiple correlation coefficient
	Constant	Dib	Dib^2			
			LOG GRADE 1			
FAS	−33.84	3.4209	—	14.0	3.8	0.72
SEL	−7.58	1.9582	—	19.8	3.1	.59
No. 1C	40.85	−.7735	—	30.0	2.3	.36
No. 2C	88.06	−4.1226	—	30.4	4.1	.76
No. 3C	12.51	−.4834	—	5.8	1.1	.44
			LOG GRADE 2			
FAS	5.46	−0.9095	0.06106	3.6	0.9	0.72
SEL	77.63	−10.6741	.42479	11.5	2.0	.51
No. 1C	9.54	1.2520	−.00122	24.7	1.3	.80
No. 2C	17.53	6.1373	.32641	43.0	3.4	.69
No. 3C	−10.17	4.1944	−.15822	17.2	4.5	.11
			LOG GRADE 3			
FAS	2.62	−0.6116	0.03749	0.4	0.4	0.73
SEL	−23.02	4.3315	−.17628	2.4	1.2	.67
No. 1C	−63.80	10.3739	−.29682	11.1	3.3	.90
No. 2C	115.23	−11.0289	.41543	46.7	6.2	.51
No. 3C	68.96	−3.0649	.02018	39.4	5.2	.65

Table 4.—Thickness distribution by lumber grade for aspen, in percent

Lumber thickness (inches)	Lumber grade				
	FAS	Selects	No. 1C	No. 2C	No. 3C
3/4	0.3	0.7	0.4	2.2	4.5
4/4	99.7	98.4	98.4	94.3	90.5
5/4	—	.9	1.1	3.1	4.4
6/4	—	—	.1	.4	.6
	Total Lumber Tally, Board Feet				
	2,608	5,084	10,447	18,207	9,320

Table 5.—Log scale, overrun, cubic volume, and lumber recovery factors of aspen sawlogs

Scaling diameter (inches)	Number of logs	Total green lumber tally	Int. 1/4″ log rule			Scribner log rule			Gross cubic log volume	Lumber recovery factor
			Gross	Net	Overrun	Gross	Net	Overrun		
		- - - - - -fbm- - - -			Percent	- - - -fbm- - - -		Percent	ft^3	
					LOG GRADE 1					
13	42	4,715	4,275	4,223	11.6	3,630	3,579	31.7	735.32	6.41
14	23	3,266	2,835	2,795	16.9	2,370	2,330	40.2	479.46	6.81
15	13	2,058	2,010	1,964	4.8	1,770	1,718	19.8	320.64	6.42
16	10	1,573	1,530	1,481	6.2	1,390	1,325	18.7	241.95	6.50
17	1	221	205	205	7.8	180	180	22.7	33.72	6.55
18	1	240	230	230	4.3	210	210	14.2	33.99	7.06
Average					10.8			29.2		6.54
					LOG GRADE 2					
10	18	1,086	995	982	10.6	830	819	32.6	177.03	6.13
11	53	3,628	3,535	3,400	6.7	2,910	2,762	31.4	597.92	6.07
12	74	6,130	5,740	5,655	8.4	4,870	4,784	28.1	937.97	6.54
13	41	3,877	3,790	3,705	4.6	3,240	3,145	23.3	603.57	6.42
14	22	2,182	2,420	2,325	−6.2	2,060	1,962	11.2	364.20	5.99
15	14	1,700	1,850	1,714	−0.8	1,650	1,515	12.2	270.51	6.28
16	5	686	730	635	8.0	660	568	20.8	114.22	6.01
17	1	125	150	122	2.5	140	101	23.8	21.19	5.90
Average					4.7			24.0		6.29
					LOG GRADE 3					
8	40	821	790	715	14.8	610	549	49.5	157.74	5.20
9	48	1,352	1,450	1,290	4.8	1,290	1,126	20.1	257.26	5.26
10	89	3,961	4,200	3,967	−0.2	3,470	3,238	22.3	724.51	5.47
11	44	2,353	2,550	2,405	−2.2	2,100	1,947	20.9	411.36	5.72
12	36	2,601	2,625	2,547	2.1	2,240	2,158	20.5	426.85	6.09
13	23	1,973	2,195	2,080	−5.1	1,900	1,757	12.3	336.49	5.86
14	5	423	620	515	−17.9	520	393	7.6	90.98	4.65
15	3	296	350	294	.7	320	251	17.9	60.86	4.86
16	3	399	445	445	−10.3	400	400	−0.2	69.63	5.73
Average					−0.6			20.0		5.59

(Continued)

Table 5.—Continued

Scaling diameter (inches)	Number of logs	Total green lumber tally	Int. 1/4″ log rule			Scribner log rule			Gross cubic log volume	Lumber recovery factor
			Gross	Net	Overrun	Gross	Net	Overrun		
			----fbm----		Percent	----fbm----		Percent	ft^3	
					ALL LOGS					
8	40	821	790	715	14.8	610	549	49.5	157.75	5.20
9	48	1,352	1,450	1,290	4.8	1,290	1,126	20.1	257.26	5.26
10	107	5,047	5,195	4,949	2.0	4,300	4,057	24.4	901.54	5.60
11	97	5,981	6,085	5,805	3.0	5,010	4,709	27.0	1,009.28	5.93
12	110	8,731	8,365	8,202	6.4	7,110	6,942	25.8	1,364.82	6.40
13	106	10,565	10,260	10,008	5.6	8,770	8,481	24.6	1,675.38	6.31
14	50	5,871	5,875	5,635	4.2	4,950	4,685	25.3	934.64	6.28
15	30	4,054	4,210	3,972	2.1	3,740	3,484	16.4	652.01	6.22
16	18	2,658	2,705	2,561	3.8	2,450	2,293	15.9	425.80	6.24
17	2	346	355	327	5.8	320	281	23.1	54.91	6.30
18	1	240	230	230	4.3	210	210	14.2	33.99	7.06
Average					4.5			24.0		6.12

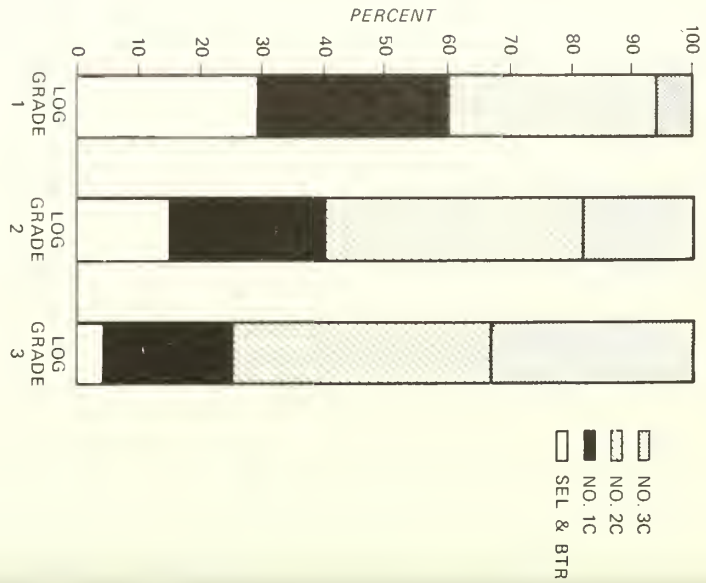

Figure 1.—Cumulative distribution of lumber grades for 13-inch aspen logs.

PART II — ASPEN TREES

Data collection

Our data base for Part II (Table 6) was 182 aspen trees selected in northern Minnesota. We have learned from past studies that 60 trees per grade, spread across the available range of dbh (diameter at breast height) and merchantable heights, is adequate for the development of lumber grade yields. We measured dbh and graded the trees before felling them. Specifications for the tree grades may be found in the Appendix. Merchantable height was measured before the logs were bucked, and was defined as the distance from the stump to the point where local-use class material stopped. A local-use log must scale at least 8 inches dib by 8 feet long, and must be one-third sound. For a detailed discussion of local-use logs, see Rast and others (1973), p. 22-23.

The trees were bucked to log lengths of 8 to 16 feet to yield the best grade possible. Of the 527 logs, 416 were Grade 3 or better and 111 were classed as construction or local-use logs. The logs were sawed and the lumber was graded as described earlier. A tally of the lumber from each tree was maintained.

Results

For each lumber grade within the three tree grades, we developed a multiple regression equation that can be used to predict green lumber grade volumes in board feet (Table 7).

The equations were of the form:

$$\text{Lumber volume} = a + b\,(\text{dbh})^2 + c\,(\text{merchantable height}) + d\,(\text{dbh}^2 \times \text{merchantable height})$$

In a few situations, selected nonsignificant variables were omitted from the equation. For example, merchantable height had no significant effect on volume of FAS lumber in Grade 2 trees because there was very little lumber of that grade above the first log.

The lumber grade volume table was developed by solving the equations for desired combinations of dbh and merchantable height (Table 8). Mean lumber volumes, standard error of the estimates, and multiple correlation coefficients are shown in Table 7. This information will prove useful to those interested in developing a scheme for sampling trees to be graded.

Use of the lumber grade volume table or equations requires the following field data for each tree:

- Tree grade
- Dbh to the nearest inch
- Merchantable height to the nearest foot as measured from the top of a 1-foot stump to the point where local-use material ends.

If the user is certain that prediction will be based on the tabular volumes, merchantable height should be estimated to the nearest half-log. However, if the equations are used to estimate lumber grade volumes, accuracy can be improved if height to the nearest foot is recorded.

The predicted green lumber grade volumes are net volumes derived from actual mill yields and should not be adjusted for cull or overrun.

If the reader is interested in a detailed discussion of the application of the tree grades for timber appraisal, refer to Hanks (1976), p. 2-6.

Table 6.—Number of aspen trees, by grade and dbh

Dbh (inches)	Tree grade		
	1	2	3
10	—	—	5
11	—	—	16
12	—	—	16
13	—	8	10
14	—	17	5
15	—	15	3
16	12	10	2
17	17	6	1
18	11	5	0
19	11	1	0
20	4	2	0
21	2	1	0
22	2	0	0

Table 7.—Regression equations, mean lumber volumes, standard error of the estimates, and correlation coefficients for aspen tree grades

Dependent variable: lumber grade	Independent variables				Mean lumber volume (board feet)	Standard error of the estimate	Multiple correlation coefficient
	Constant	Dbh^2	Merchantable height	$Dbh^2 \times$ merchantable height			
			TREE GRADE 1 (Basis: 59 Trees)				
FAS	−1.4	0.04277	−0.5865	0.003084	27.2	24.9	0.41
SEL	−16.1	.18446	—	—	43.0	19.7	.56
No. 1C	−9.4	.13571	−0.2518	.003311	63.9	23.7	.66
No. 2C	3.5	.03034	2.0224	.002009	110.9	32.7	.72
No. 3C	−13.7	—	.9432	—	20.5	17.2	.55
			TREE GRADE 2 (Basis: 65 Trees)				
FAS	−1.4	0.02737	—	—	5.1	7.4	0.24
SEL	11.6	.00719	−0.4004	0.002093	16.8	14.2	.33
No. 1C	1.9	.05961	−0.8487	.006752	42.6	25.0	.62
No. 2C	9.4	−.04741	.3155	.011053	101.4	29.0	.81
No. 3C	−3.5	—	.6157	—	18.2	15.6	.46
			TREE GRADE 3 (Basis: 58 Trees)				
FAS	0.7	—	—	—	0.7	2.1	—[a]
SEL	−3.2	0.04755	0.0671	−0.000305	4.6	6.7	0.28
No. 1C	−0.8	.08580	−0.3069	.001968	12.3	10.4	.53
No. 2C	1.7	.07881	.9367	.004738	63.8	20.2	.76
No. 3C	−6.8	−.03061	.3272	.004469	18.9	14.0	.69

[a] For this lumber grade, the mean lumber volume was used instead of a regression equation. Therefore, multiple correlation coefficient is undefined.

Table 8.—Green lumber grade volumes for graded aspen trees, in board feet

bh (inches)	Lumber grade				
	FAS	SEL	No. 1C	No. 2C	No. 3C
		TREE GRADE 1			
		1 LOG			
6	12.7	31.1	34.8	51.8	1.3
7	15.8	37.2	41.0	53.8	1.3
8	19.0	43.7	47.6	56.0	1.3
9	22.4	50.5	54.6	58.3	1.3
0	26.0	57.7	62.0	60.8	1.3
1	29.8	65.2	69.7	63.3	1.3
2	33.7	73.2	77.8	66.0	1.3
		TREE GRADE 1			
		1½ LOGS			
6	14.3	31.1	39.6	72.1	8.9
7	18.2	37.2	46.7	74.7	8.9
8	22.3	43.7	54.2	77.4	8.9
9	26.6	50.5	62.2	80.3	8.9
0	31.1	57.7	70.6	83.4	8.9
1	35.9	65.2	79.4	86.6	8.9
2	40.9	73.2	88.6	90.0	8.9
		TREE GRADE 1			
		2 LOGS			
6	16.0	31.1	44.3	92.4	16.4
7	20.6	37.2	52.3	95.5	16.4
8	25.6	43.7	60.8	98.8	16.4
9	30.8	50.5	69.7	102.3	16.4
0	36.3	57.7	79.1	106.0	16.4
1	42.1	65.2	89.0	109.9	16.4
2	48.2	73.2	99.4	113.9	16.4
		TREE GRADE 1			
		2½ LOGS			
6	17.6	31.1	49.1	112.7	24.0
7	23.1	37.2	58.0	116.3	24.0
8	28.9	43.7	67.3	120.2	24.0
9	35.0	50.5	77.3	124.3	24.0
0	41.5	57.7	87.7	128.6	24.0
1	48.3	65.2	98.7	133.1	24.0
2	55.4	73.2	110.2	137.9	24.0
		TREE GRADE 1			
		3 LOGS			
6	19.2	31.1	53.9	133.0	31.5
7	25.5	37.2	63.6	137.1	31.5
8	32.2	43.7	73.9	141.6	31.5
9	39.2	50.5	84.8	146.3	31.5
0	46.6	57.7	96.3	151.2	31.5
1	54.5	65.2	108.4	156.4	31.5
2	62.6	73.2	121.1	161.9	31.5
		TREE GRADE 1			
		3½ LOGS			
6	20.8	31.1	58.6	153.3	39.0
7	27.9	37.2	69.2	158.0	39.0
8	35.4	43.7	80.5	163.0	39.0
9	43.4	50.5	92.4	168.3	39.0
0	51.8	57.7	104.9	173.8	39.0
1	60.6	65.2	118.0	179.7	39.0
2	69.9	73.2	131.9	185.8	39.0

Dbh (inches)	Lumber grade				
	FAS	SEL	No. 1C	No. 2C	No. 3C
		TREE GRADE 2			
		1 LOG			
13	3.1	12.0	16.6	36.3	6.3
14	3.9	13.1	21.2	39.8	6.3
15	4.7	14.3	26.0	43.5	6.3
16	5.5	15.5	31.2	47.6	6.3
17	6.4	16.9	36.7	51.8	6.3
18	7.4	18.3	42.6	56.4	6.3
19	8.4	19.8	48.8	61.2	6.3
20	9.5	21.4	55.3	66.2	6.3
21	10.6	23.1	62.2	71.5	6.3
22	11.8	24.8	69.4	77.1	6.3
		TREE GRADE 2			
		1½ LOGS			
13	3.1	11.6	19.0	53.8	11.3
14	3.9	13.2	24.9	59.6	11.3
15	4.7	14.8	31.4	66.0	11.3
16	5.5	16.6	38.2	72.7	11.3
17	6.4	18.5	45.6	79.9	11.3
18	7.4	20.5	53.3	87.5	11.3
19	8.4	22.7	61.5	95.6	11.3
20	9.5	24.9	70.2	104.1	11.3
21	10.6	27.3	79.3	113.0	11.3
22	11.8	29.7	88.8	122.4	11.3
		TREE GRADE 2			
		2 LOGS			
13	3.1	11.3	21.3	71.2	16.2
14	3.9	13.3	28.7	79.5	16.2
15	4.7	15.4	36.7	88.4	16.2
16	5.5	17.7	45.3	97.9	16.2
17	6.4	20.2	54.4	108.0	16.2
18	7.4	22.8	64.0	118.7	16.2
19	8.4	25.5	74.2	130.0	16.2
20	9.5	28.4	85.0	142.0	16.2
21	10.6	31.4	96.3	154.5	16.2
22	11.8	34.6	108.1	167.7	16.2
		TREE GRADE 2			
		2½ LOGS			
13	3.1	10.9	23.6	88.7	21.1
14	3.9	13.3	32.5	99.4	21.1
15	4.7	16.0	42.1	110.8	21.1
16	5.5	18.8	52.3	123.0	21.1
17	6.4	21.8	63.2	136.1	21.1
18	7.4	25.0	74.7	149.9	21.1
19	8.4	28.3	86.9	164.5	21.1
20	9.5	31.9	99.8	179.9	21.1
21	10.6	35.6	113.3	196.1	21.1
22	11.8	39.5	127.5	213.0	21.1
		TREE GRADE 2			
		3 LOGS			
13	3.1	10.5	26.0	106.2	26.0
14	3.9	13.4	36.3	119.2	26.0
15	4.7	16.5	47.5	133.2	26.0

Table 8.—Continued

Dbh (inches)	Lumber grade				
	FAS	SEL	No. 1C	No. 2C	No. 3C
16	5.5	19.9	59.4	148.2	26.0
17	6.4	23.4	72.0	164.1	26.0
18	7.4	27.2	85.5	181.1	26.0
19	8.4	31.2	99.7	198.9	26.0
20	9.5	35.4	114.6	217.8	26.0
21	10.6	39.8	130.3	237.6	26.0
22	11.8	44.4	146.8	258.4	26.0
		TREE GRADE 3			
		1 LOG			
10	0.7	2.1	6.0	32.1	2.5
11	.7	3.0	8.4	35.4	3.3
12	.7	4.0	11.1	38.9	4.3
13	.7	5.0	14.0	42.8	5.3
14	.7	6.2	17.2	46.9	6.4
15	.7	7.4	20.6	51.4	7.6
16	.7	8.7	24.3	56.2	8.9
17	.7	10.2	28.1	61.3	10.2
		TREE GRADE 3			
		1½ LOGS			
10	0.7	2.4	5.1	43.4	8.7
11	.7	3.2	7.9	47.4	10.3
12	.7	4.2	10.9	51.9	12.0
13	.7	5.2	14.3	56.7	14.0
14	.7	6.2	17.8	61.9	16.0
15	.7	7.4	21.7	67.5	18.2
16	.7	8.7	25.8	73.4	20.6
17	.7	10.0	30.2	79.8	23.2

Dbh (inches)	Lumber grade				
	FAS	SEL	No. 1C	No. 2C	No. 3C
		TREE GRADE 3			
		2 LOGS			
10	0.7	2.7	4.2	54.7	14.9
11	.7	3.5	7.3	59.5	17.2
12	.7	4.3	10.7	64.8	19.8
13	.7	5.3	14.5	70.6	22.6
14	.7	6.3	18.5	76.8	25.6
15	.7	7.4	22.8	83.5	28.9
16	.7	8.6	27.4	90.6	32.4
17	.7	9.8	32.3	98.2	36.1
		TREE GRADE 3			
		2½ LOGS			
10	0.7	3.0	3.3	66.0	21.1
11	.7	3.7	6.8	71.6	24.2
12	.7	4.5	10.5	77.8	27.6
13	.7	5.4	14.7	84.5	31.3
14	.7	6.4	19.1	91.7	35.3
15	.7	7.4	23.9	99.5	39.6
16	.7	8.5	29.0	107.8	44.2
17	.7	9.7	34.4	116.7	49.1
		TREE GRADE 3			
		3 LOGS			
12	0.7	4.7	10.4	90.7	35.3
13	.7	5.5	14.9	98.4	39.9
14	.7	6.4	19.7	106.6	44.9
15	.7	7.4	25.0	115.5	50.2
16	.7	8.4	30.6	125.0	55.9
17	.7	9.5	36.5	135.1	62.0

APPENDIX

Forest Service Standard Grades for Hardwood Factory Lumber Logs[a]

Grading Factors		Log grades							
		F1			F2				F3
Position in tree		Butts only	Butts & uppers		Butts & uppers				Butts & uppers
Scaling diameter, inches		13-15[b]	16-19	20+	11+[c]	12			8+
Length without trim, feet			10+		10+	8-9	10-11	12+	8+
Required clear cuttings[d] on each of 3 best faces[e]	Min. length, feet	7	5	3	3	3	3	3	2
	Max. number	2	2	2	2	2	2	3	No limit
	Min. proportion of log length required in clear cutting	5/6	5/6	5/6	2/3	3/4	2/3	2/3	1/2
Maximum sweep & crook allowance	For logs with less than ¼ of end in sound defects	15%			30%				50%
	For logs with more than ¼ of end in sound defects	10%			20%				35%
Maximum scaling deduction		40%[f]			50%[g]				50%
End defect:		See special instructions (page 18)							

[a] From USDA Forest Service Research Paper FPL-63.
[b] Ash and basswood butts can be 12 inches if they otherwise meet requirements for small #1's.
[c] Ten-inch logs of all species can be #2 if they otherwise meet requirements for small #1's.
[d] A clear cutting is a portion of a face, extending the width of the face, that is free of defects.
[e] A face is ¼ of the surface of the log as divided lengthwise.
[f] Otherwise #1 logs with 41-60% deductions can be #2.
[g] Otherwise #2 logs with 51-60% deductions can be #3.

Reprinted from Rast and others (1973), p. 11.

Hardwood Tree Grades for Factory Lumber

Grade factor	Tree grade 1			Tree grade 2		Tree grade 3
Length of grading zone (feet)	Butt 16			Butt 16		Butt 16
Length of grading section[a] (feet)	Best 12			Best 12		Best 12
Dbh, minimum (inches)	16[b]			13		10
Diameter, minimum inside bark at top of grading section (inches)	13[b]	16	20	11[c]	12	8
Clear cuttings (on the 3 best faces):[d]						
Length, minimum (feet)	7	5	3	3	3	2
Number on face (maximum)		2		2	3	(e)
Yield in face length (minimum)		5/6		4/6		3/6
Cull deduction, including crook and sweep but excluding shake, maximum within grading section (percent)		9		9[f]		50

[a] Whenever a 14- or 16-foot section of the butt 16-foot log is better than the best 12-foot section, the grade of the longer section will become the grade of the tree. This longer section, when used, is the basis for determining the grading factors such as diameter and cull deduction.

[b] In basswood and ash, dib at top of grading section must be 12 inches and dbh must be 15 inches.

[c] Grade 2 trees can be 10 inches ib at top of grading section if otherwise meeting surface requirements for small grade 1s.

[d] A clear cutting is a portion of a face free of defects, extending the width of the face. A face is one-fourth of the surface of the grading section as divided lengthwise.

[e] Unlimited.

[f] Fifteen percent crook and sweep or 40 percent total cull deduction are permitted in grade 2 if size and surface of grading section qualify as grade 1. If rot shortens the required clear cuttings to the extent of dropping the butt log to grade 2, do not drop the tree's grade to 3 unless the cull deduction for rot is greater than 40 percent.

Reprinted from Hanks (1976), p. 2.

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AN ECONOMETRIC ANALYSIS OF THE U.S. HARDBOARD MARKET

by Albert T. Schuler

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Abstract

An econometric model of U.S. hardboard consumption was developed to identify the major variables affecting hardboard consumption and price. The variables identified were housing starts, residential improvement activity, disposable personal income, hardwood plywood price, productivity, pulpwood and residue price, hardboard tariff, and power cost. Disposable personal income was the most important of these variables, affecting both consumption and price. Annual projections show consumption increasing by 60 percent and price by 133 percent (over 1977 levels) by the year 1990.

INTRODUCTION

THE U.S. HARDBOARD MARKET is supplied by two sources. Since 1950, domestic producers have been providing approximately 90 percent of U.S. consumption, while imports made up the remainder. This study analyzes the aggregate market for hardboard (treated and untreated) consumed in the United States. Consumption is defined as domestic production plus imports minus exports.

The domestic hardboard industry set a production record in 1977 with an output estimated at 7.4 billion square feet (1/8-inch basis). United States consumption has increased 65 percent since 1970, and indications are that the increase will continue, but at a slower rate. Domestic wholesale hardboard prices have increased 53 percent since 1970, although the increase in 1977 was a modest 3.3 percent. The domestic hardboard industry must learn more about the structure of its markets to continue its rapid expansion. Price and consumption projections can facilitate long-range capital investment planning decisions which are particularly crucial to this capital-intensive, energy-dependent industry.

Hardboard has been described as having a thousand uses, ranging from wood panel products inside and outside the home to numerous uses in the furniture industries. However, the major market is exterior siding which consumes approximately 25 percent of domestic hardboard produced.

The domestic hardboard industry has 26 plants producing hardboard products and six plants producing both hardboard and insulation board. The 26 plants have an annual capacity of 7.8 billion square feet (1/8-inch basis).

Complete quantitative market information is lacking, which complicates annual and long-term planning in the domestic hardboard industry. What is needed is an adequate supply-demand prediction model for the industry. Although most firms have short- term intelligence in the form of order backlogs, marketing feedbacks, etc., annual planning would benefit from knowledge of the important factors that affect consumption and price of hardboard. For example, information that consumption of hardboard products varies with disposable personal income would justify monitoring projections of that variable and altering production levels accordingly. Quantification of the relationships between hardboard consumption or price levels and other demand-supply variables can provide the industry with "early warning" information which may help avoid major production errors.

Accurate long-term planning (10 to 15 years) is necessary to the survivial of individual firms and the industry itself. This type of planning requires estimates of future consumption and price levels to determine capital needs.

Reliable planning should result in adequate hardboard supplies to meet anticipated demand, and thus keep consumer prices from spiraling. Consumption projections are also needed by forest planners to evaluate current forest programs, establish timber growth goals, and aid in formulating forest policies and proposed programs.

Specific objectives of the study reported here were: (1) to identify variables that are good predictors of hardboard supply and demand by developing a supply-demand model; (2) to quantify the relationships between these variables and U.S. hardboard consumption and price by developing projection equations; and (3) to project annual equilibrium U.S. consumption and price levels to the year 1990.

FRAMEWORK OF ANALYSIS AND METHODOLOGY

An equilibrium model consisting of a demand and supply equation and an identity was developed to study the U.S. hardboard market. The identity is necessary for demand-supply equilibrium. The general form of the linear model is:

$$\text{Demand} = \alpha_d P + \beta_o + \beta_1 \chi_{d1} + \ldots + \beta_p \chi_{dp} + e_d$$

$$\text{Supply} = \alpha_s P + \gamma_o + \gamma_1 \chi_{s1} + \ldots + \gamma_q \chi_{sq} + e_s$$

$$\text{Demand} = \text{Supply} = \text{Consumption}$$

where:

Consumption = domestic production + imports − exports
P = hardboard price
$\chi_{d1} \ldots \chi_{dp}$ = demand variables
$\chi_{s1} \ldots \chi_{sq}$ = supply variables
α_d, α_s = regression coefficients for price
$\beta_1 \ldots \beta_p$ = regression coefficients for independent demand variables
$\gamma_1 \ldots \gamma_q$ = regression coefficients for independent supply variables
e_d = demand error term
e_s = supply error term
β_o, γ_o = intercept terms for demand and supply equations, respectively

The model depicted is an equilibrium model that accounts for the interaction between demand and supply and the interdependence of prices and consumption. The data base was annual observations of each variable over the sample period 1950 to 1977. The data sources used were, for housing starts, value of residential improvements, disposable personal income, and power costs, U.S. Bureau of Census (1950-1977); for productivity, U.S. Bureau of Census (1954-1972); for pulpwood and residue prices, hardwood plywood prices, hardboard consumption, and hardboard price, Phelps (1977).

The two-stage least squares (2SLS) procedure was used to estimate the parameters in the demand and supply equations. This procedure is specifically designed for over-identified simultaneous systems (Christ 1966). Two-stage least squares was selected over other simultaneous equation procedures because it reduces computation and computer algorithms such as the SYSREG routine in SAS-76 (Barr et al. 1976) are readily accessible and inexpensive to use.

SPECIFICATION OF HARDBOARD MARKET MODEL

The first step in developing a U.S. hardboard market model was to identify major factors that influence demand and supply. Economic theory provided a basic framework and discussions with knowledgeable industry sources provided additional information.

The second step was to select variables that could represent the factors identified in step one. Selected variables had to be measurable and projections of them had to be available. Projections are necessary because they are needed to project hardboard consumption and price.

The major factors assumed to affect hardboard demand and supply, initial candidate variables selected to represent these factors, the expected relationships between the variables and supply and demand, and their units of measurement are presented in Tables 1 and 2.

Table 1.—Major demand factors, variables, expected relationships between variables and demand, and units for the hardboard model. The designations in parentheses in the variable column represent the same variables in equations 1, 2, 3, and 4

Factor	Variable(s)	Expected relationship	
1. U.S. building construction	a. Housing starts (starts)	Positive	1,000 units
	b. Residential improvements & repairs (improvements)	Positive	$ Million, 1967
	e. Nonresidential building construetion (NR construction)	Positive	$ Million, 1967
2. U.S. furniture manufaeture	a. Furniture produetion index (furniture)	Positive	Index·(1967 = 100)
3. U.S. income	a. Disposable personal ineome (income)	Positive	$ Billion, 1967
4. Substitute materials	a. Weighted average of imported and domestic hardwood plywood price (hardwood plywood price)	Positive	Index (1967 = 100)
5. Hardboard price	a. Weighted average of treated and untreated domestie wholesale hardboard prices (price)	Negative	Index (1967 = 100)
	b. Imported wholesale hardboard priee (import priee)	Negative	Index (1967 = 100)

Table 2.—Major supply factors, variables, expected relationships between variables and supply, and units for the hardboard model. Designations in parentheses in the variable column represent the same variables in equations 1, 2, 3, and 4

Factor	Variable(s)	Expected relationship	Units
1. Production costs	a. Weighted average of pulpwood and plant residuc prices (wood)	Negative	Index (1967 = 100)
	b. Average of eleetricity and natural gas prices (energy)	Negative	Index (1967 = 100)
	e. Produetivity in hardboard industry (produetivity)	Positive	Value of shipments in 1967 dollars per man-hour of production workers
2. Hardboard tariff	a. U.S. hardboard import tariff (tariff)	Negative	Percent ad valorem
3. Domestic hardboard price	a. Weighted average of treated and untreated wholesale domestie hardboard price (priee)	Positive	Index (1967 = 100)

ESTIMATED DEMAND AND SUPPLY EQUATIONS

Parameters of a linear demand-supply equation model were estimated by the 2SLS estimating procedure presented by Theil (1975). The following information was used in judging whether or not candidate variables should be retained in the estimated model: (1) the size of the beta coefficient in relation to its standard error—the coefficient should be greater than or equal to the standard error (ordinarily the "t-statistic" is used, however, this statistic is only asymptotically valid for 2SLS); (2) the significance of the Dubin-Watson D statistic which was used to test for serial correlation in the residuals; (3) whether the estimated model met identification requirements; and (4) whether the parameters in the model had the expected sign.

Estimating the demand equation presented some difficulties in that some of the expected relationships were not substantiated. The furniture production variable had a negative sign when a positive sign was expected, and the beta coefficient was less than its standard error. One possible reason is that disposable personal income and the furniture production index are highly correlated (r = .98). Dropping disposable income from the demand equation resulted in the Durbin-Watson D Statistic approaching significance. Therefore, disposable income was retained and furniture production was deleted. I believe disposable income is a more appropriate variable because income levels are probably the major determinant of furniture consumption, hence the disposable income variable should partially account for variation in hardboard demand due to changes in furniture production.

The nonresidential building activity variable also had a negative sign when positive was expected, and the beta coefficient was less than its standard error. I believe the problem here is that this variable is not specific enough to account for variation in hardboard demand, hence the variable was deleted from the model.

The hardboard import price variable had a positive sign when negative was expected, and its beta coefficient was less than the standard error. I believe that the influence of imports is probably stronger on the supply side of the market and, therefore, deleted the variable from the demand side of the model.

Residential improvement activity had a beta coefficient less than its standard error. However, it had the expected sign, and I felt that because of the growing importance of this building market, the variable should be retained in the demand equation. The remainder of the expected demand relationships met the statistical and economical criteria for retaining variables.

Hardwood plywood price was treated as an independent variable for purposes of this study. Although plywood price probably affects demand for hardboard through product substitution, activity in the hardboard market does not affect plywood prices. The dominant factor influencing hardwood plywood price is the considerable import volume, which has averaged 49 percent of U.S. consumption over the past 10 years.

Estimating the supply equation presented fewer difficulties. All coefficients had the expected sign. The pulpwood and plant residue price variable had a standard error greater than its beta coefficient, but because of the importance of wood raw material costs in making supply decisions, I felt the variable should be retained in the model.

Serial correlation among residuals was not significant in either the demand or supply equations suggesting that the linear model was adequate, and that no major variables were missing from the model.

Estimated model

The final model estimated using the 2SLS procedure was:

(1) Demand = $-7238110.1 - 13749.9$ price + 1098.9 starts + 26.3 improvements + 29405.9 hardwood plywood price + 14197.2 income

$D = 2.09$

$R^2 = .994$ SE = 185,484 MFT^2 (1/8-inch basis)

(2) Supply = $4873536.7 + 31957.5$ price $- 669956.6$ tariff + 268860.9 productivity $- 7387.3$ energy $- 78662.1$ wood

$D = 1.79$

$R^2 = .979$ SE = 354,822 MFT^2 (1/8-inch basis)

HARDBOARD CONSUMPTION AND PRICE PROJECTIONS

The demand and supply equations (1 and 2) were solved simultaneously to yield reduced form equations for hardboard price and consumption.

(3) Consumption = − 3594632 + 768.32 starts + 18.39 improvements + 20559.9 hardwood plywood price + 9926.3 income − 201539 tariff + 80879.9 productivity − 2222.3 energy − 23663.5 wood

(4) Price = − 264.98 + .024 starts + .00057 improvements + .64335 hardwood plywood price + .3106 income + 14.657 tariff − 5.882 productivity + .1616 energy + 1.721 wood

Evaluation of residuals in the projection equations

The projection equations (3 and 4) were evaluated to determine how closely they fitted the sample data. The closeness of the fit will provide some measure of their potential predictive ability beyond the sample data base. Three measures of fit were calculated for the consumption and price projection equations (Table 3). Values near zero imply a good fit to the sample data. In each case, actual values for independent variables were used to calculate the predicted (P) values.

Results listed in Table 3 indicate that the projection equations fit the sample data extremely well. Although these three measures are ordinarily used to evaluate predictive ability beyond the data base, they are useful in evaluating the fit of projection equations over the sample period.

Elasticity measures

The relative importance of each variable in the model can be determined by its respective elasticity; that is, the percent change in price or consumption associated with a 1 percent change in one of the predetermined variables, holding everything else constant. For example, a 1 percent increase in real disposable personal income (with a consumption elasticity of 1.36) could increase hardboard consumption by 66,197,000 square feet (1/8-inch basis). However, elasticity is only a partial measure of impact because disposable income, for example, may affect other variables within and outside the hardboard system that could offset or amplify the resulting impact on consumption.

The following elasticities were calculated for consumption and price of hardboard and are based on average values for each variable over the sample period.

Consumption		*Domestic hardboard price*	
Income	1.36	Income	1.46
Hardwood plywood price	.64	Tariff	1.32
Tariff	−.53	Productivity	−.82
Starts	.34	Hardwood plywood price	.69
Productivity	.33	Starts	.36
Wood	−.12	Wood	.29
Energy	−.07	Energy	.18
Improvements	.07	Improvements	.07

Table 3.—Theil's (1975) υ-coefficient, mean percentage error (MPE) and mean absolute percentage error (MAPE) for consumption and price projection equations over the sample period.

Projection equation	υ-coefficient[a]	MPE[b]	MAPE[c]
Consumption	.034	.0057	.114
Price	.076	.0059	.2100

[a] $$\upsilon = \left[\frac{\sum_{i=1}^{N} (P-A)^2}{\sum_{i=1}^{N} A^2} \right]^{1/2}$$

A = actual values
P = predicted values
N = sample size

[b] $$MPE = \frac{1}{N} \left[\frac{\sum P-A}{\sum A} \right] X\ 100$$

[c] $$MAPE = \frac{1}{N} \left[\frac{\sum |P-A|}{\sum A} \right] X\ 100$$

Both price and quantity are most sensitive to disposable personal income and least sensitive to residential improvement activity. The hardboard tariff had a surprisingly strong impact on domestic hardboard price, whereas energy and wood costs were less important. As expected, productivity was more important in affecting price than consumption. Generally, quantity is most sensitive to demand variables, although price was not similarly dominated by supply variables as one would expect.

Projections for predetermined variables

Projections had to be obtained for the predetermined variables before projections beyond 1977 could be made for consumption and price of hardboard. Wherever possible, forecasts by other sources were used, e.g., Marcin's (1977) housing start projections. Many government (e.g., U.S. Bureau of Economic Analysis 1974) and private sources project real disposable personal income to grow at an annual rate of approximately 3 percent. Residential improvement and repair activity has picked up considerable momentum in the 1970's in response to rapidly escalating housing construction costs and new home mortgage rates. The real rate of increase between 1970 and 1977 has averaged 3 percent annually, and this rate was used for the projection period.

Electricity and natural gas prices have increased at an average annual rate of 37 percent since 1973. However, for projection purposes, I assumed that energy costs will be more in line with the average annual rate of increase (10 percent) established over the sample period (1950 to 1977). For the remaining independent variables in the model, I assumed that each would continue at the annual rates of increase established over the period 1970 to 1977: deflated pulpwood and residue prices, 2 percent; productivity, 4 percent; and hardwood plywood prices, 3.08 percent. I assumed that the hardboard tariff would continue at the average yearly rate established during the period 1970 to 1977 (8.4 percent).

For projecting consumption and price of hardboard, I used the above rates as the basis for the medium-level projections. However, to provide some flexibility, projections were also made under somewhat more optimistic (high-level) and pessimistic (low-level) economic conditions. The independent variables in the model can fluctuate considerably from their norms; values of plus or minus 15 percent are not unusual. Therefore, the high-level projections are based on my assumption that the independent variables will increase at a rate 15 percent greater than the medium-level rate. For example, I assumed that real disposable personal income would increase at a 3.45 percent rate, instead of the medium-level rate of 3 percent. The low-level projections are based on the assumption that the independent variables will increase, but at a rate 15 percent less than the medium level rate. The corresponding rate for income, for example, was 2.55 percent. Similar assumptions were made for the other independent variables in the model.

Projections for quantity and price

Hardboard consumption and price were projected to the year 1990 (Tables 4 and 5). Consumption is projected to increase 60 percent (over the 1977 level) while the price index is projected to increase 133 percent by 1990. These figures were translated into average annual rates of increase of 4.6 and 10 percent, respectively, for quantity and price. The projected trends are the same as those of the past 10 years, when consumption and price

Table 4.—U.S. consumption projections for hardboard in thousand of square feet, 1/8-inch basis

Year	High	Medium	Low
1980	9,024,045	8,902,891	8,784,005
1985	11,115,160	10,762,380	10,411,190
1990	13,201,710	12,527,010	11,875,460

U.S. Consumption = domestic production + imports – exports

Table 5.—Domestic hardboard price index projections. 1967 = 100 (average of treated and untreated)

Year	High	Medium	Low
1980	229.2	198.9	171.5
1985	310.3	267.9	226.3
1990	429.4	359.5	295.4

increased at annual rates of 8.2 and 5.7 percent, respectively; however, consumption is no longer increasing faster than price. One possible reason for the rate reversal is that hardboard is no longer the new product it once was, and its product life cycle may be approaching a more mature stage. With most consumer products, demand growth eventually slows after initial rapid expansion.

CONCLUSIONS

The hardboard market model developed in this study can be most useful for long-range (10 to 15 years) planning because projections for consumption and price can help provide industry planners with trend information they need for capital investment decisions. Current industry capacity is approximately 7.8 billion square feet (1/8-inch basis), and according to my analysis, will have to be increased 60 percent by 1990 if projected consumption is to be met from domestic production. If imports account for 11 percent of consumption (as they have for the past 10 years), domestic plant capacity will still have to be increased 43 percent. If price increases at the projected 10 percent annual rate, this could provide some incentive to expand plant capacity.

The market model also provides useful annual planning information in the form of consumption and price elasticities. Calculated elasticities show hardboard consumption and price to be most sensitive to disposable personal income. Income is monitored closely by government agencies and projections are developed frequently. These projections, in conjunction with the elasticity information from this model, could be used by the hardboard industry to detect early warning signs of changing market conditions.

A concern with the study is that the projection equations were not tested adequately for predictive ability. Unfortunately, sufficient observations could not be reserved from the available time series. However, an analysis of the residuals of the projection equations over the sample period indicated a good fit. Therefore, the accuracy of the projections beyond 1977 will depend on the accuracy of the independent variable projections and the degree of future structural changes in the hardboard industry. Nevertheless, results from this study suggest the potential of econometric models to provide forest planners with valuable information on future trends in the wood-using industries. These estimates are needed to determine future forest resource requirements and to evaluate current and proposed forest programs.

When using any econometric model, one must recognize that structural changes can occur. A variety of developments could significantly change the estimated relationships among the variables in the demand and supply equations. If changes occur, altered conditions will necessitate a new look at any conclusions drawn from the study. There may be a need to re-estimate the model and re-project consumption and price periodically.

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by Robert M. Frank and Barton M. Blum

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The Selection System of Silviculture in Spruce-Fir Stands—Procedures, Early Results, and Comparisons with Unmanaged Stands

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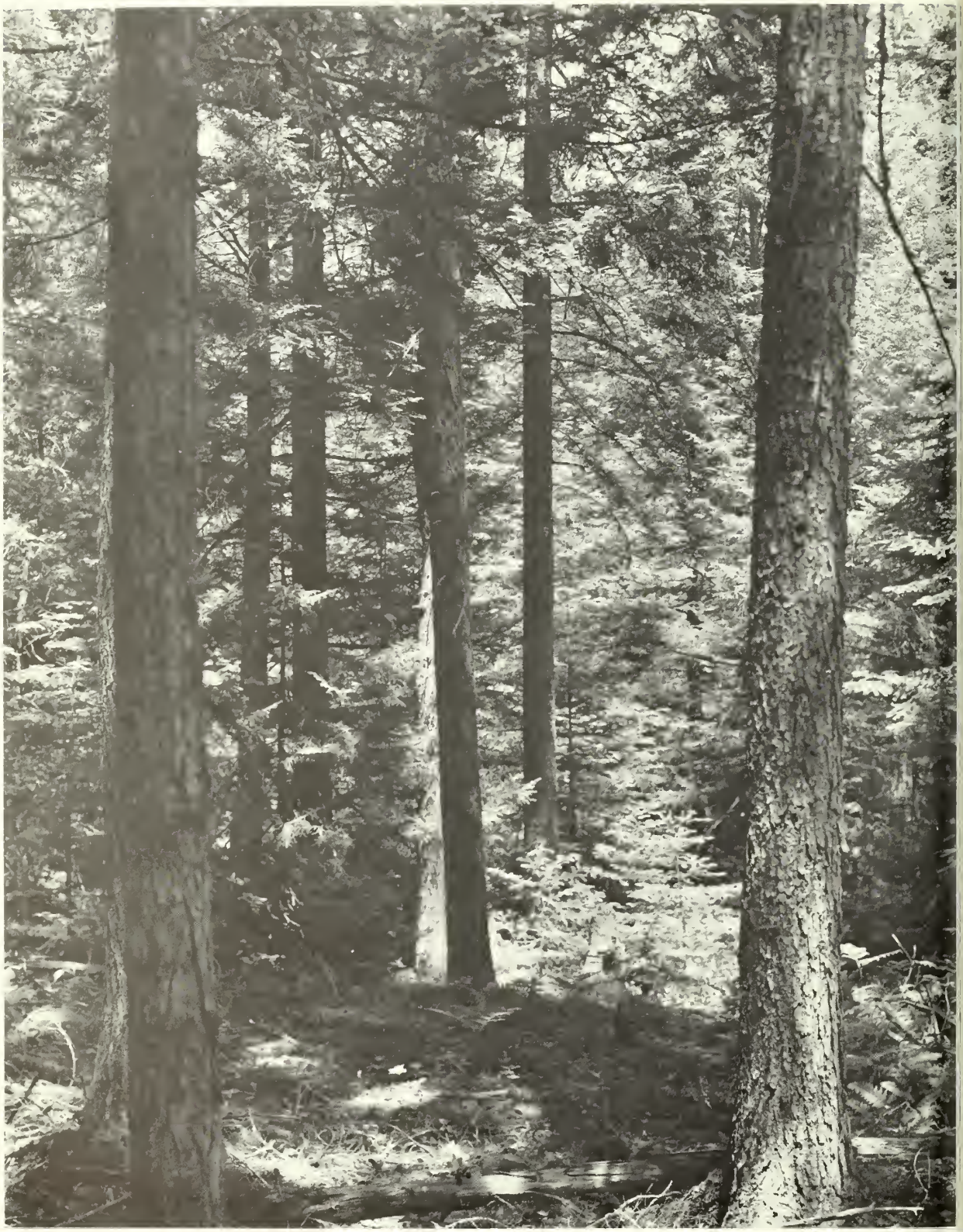
The Selection System of Silviculture in Spruce-Fir Stands—Procedures, Early Results, and Comparisons with Unmanaged Stands

by Robert M. Frank and Barton M. Blum

Abstract

Early results after 20 years of record keeping indicate that spruce-fir stands will respond to the selection system of silviculture. Stand quality is improved, species composition can be altered, diameter-class distribution approaches a stated goal, stand density is controlled, and yields are increased. Selection silviculture in spruce-fir can now be compared to early results from unregulated harvesting (commercial clearcutting) and no management for wood products (woodland preserve or wilderness). Lack of direct comparisons between selection silvicultural management and no management in spruce-fir stands has been partly responsible for the limited acceptance of the method.

Figure 1. A managed stand resulting from selection system silviculture.



INTRODUCTION

THE SELECTION SYSTEM of silviculture, or uneven-age silviculture, is the periodic marking and harvesting of single trees or small groups of trees by diameter groups to provide a steady flow of forest products. This system requires the periodic removal of defective, slow-growing, or otherwise unwanted trees as part of the logging operation, and creates and maintains an uneven-aged stand of trees with a specific diameter distribution. Other long-term goals of the selection system are improvement of species composition, stand density, and stand quality. The system encourages the continuous establishment of natural reproduction and is particularly suitable for tolerant species such as the spruces and balsam fir. When aesthetics are important, it has the advantage of maintaining a continuous forest cover on the land.

In this paper we present the silvicultural procedures needed to apply the selection system in spruce-fir stands, and include comparative data from 20 years of experience in managing spruce and fir under the selection system, commercial clearcutting, and no management in a woodland preserve. The study is being conducted on the Penobscot Experimental Forest near Bangor, Maine (Figs. 1 and 2).

Figure 2. An unmanaged stand.

HOW TO BEGIN THE SELECTION SYSTEM OF SILVICULTURE

An inventory of the forest stand sets the stage for the initiation of any silvicultural system. The first step is to delineate each stand to be treated. Stands should be small enough to be reasonably uniform in characteristics such as species composition and diameter distribution, yet large enough to permit efficient harvesting. Utilizing streams and roads as boundaries minimizes the cost of administering boundaries.

A series of sample plots may be used to inventory stand characteristics. Or, for the smaller ownerships, the owner may desire to make 100-percent inventories. The sampling procedure can be random or systematic. For the smaller ownerships, a minimum of 10 sample plots should be taken or at least 1 per acre. In stands with uniform characteristics, this intensity of sampling should provide reliable estimates of numbers of trees, volume, basal area, species composition, diameter distribution and quality, on a per-acre basis. These can then be used to describe stand characteristics. If growth rates are desired, they can also be obtained from increment cores taken from a random selection of trees.

The inventory results, when compared with stand characteristic goals, form the blueprint for the work that must be accomplished during the initial operations. Later inventories will also serve as major tools for keeping the management program in line with the stated goals.

THE STAND CHARACTERISTICS GOALS

The primary timber management goal should be the perpetual flow of quality products from each stand in the forest ownership. This goal is attained with selection silviculture when each stand contains quality trees of desirable species in a balanced diameter-class distribution. How quickly this goal is realized depends not only on the original condition of the stand, but also on how often the stand is entered—the operating interval or cutting cycle.

Not all stands of trees are suited for the immediate application of the selection system of silviculture. Those highgraded in the past, where the best trees were removed and the poorest trees remain, are often depleted and deteriorating. Such areas have a high percentage of their growing-stock volume in cull trees, over-mature trees, or non-merchantable species and might better be regenerated by the clearcut or shelterwood systems than managed by the selection system. The conversion of even-aged stands to the selection system is also of doubtful practical value.

Nevertheless, these marginal stands can be cultured into operable selection stands if the owner is willing to accept the additional costs and time needed to condition them.

The selection of an appropriate operating interval depends on the degree of silvicultural management desired and the economics of the operation. A short interval gives a smaller periodic harvest and leaves more residual growing stock. With short operating intervals, loss of wood due to mortality may be reduced to near zero because diseased and other poor-risk trees are removed before they die. Because the general health of the stand is maintained damage is minimized from epidemics caused by insects or disease. A short operating interval means that the forest can be looked after more closely and higher production is likely.

However, if periodic production is low, a short operating interval may not be economical. Also, short intervals with frequent stand entries may result in relatively more logging damage to the residual stand, including regeneration.

Short operating intervals, less than 15 years, should result in fairly rapid attainment of initial stand characteristic goals. These goals should approximate the following:

a. *Stand quality.* Gross volume in cull trees (less than 50 percent merchantable), should be reduced to less than 5 percent of total stand volume. Defects in merchantable trees should be kept at a minimum.

b. *Species composition.* Listed below is a species composition goal suitable for a wide range of spruce-fir types. This goal is attainable on sites with impeded drainage and few hardwoods. These sites have the potential to produce cover types containing at least 50 percent spruce- fir.

Species	*Basal area (percent)*
Spruces - red, white, black *Picea rubens* Sarg., *P. glauca* (Moench) Voss, *P. mariana* (Mill.) B.S.P.	35 - 65
Balsam fir *Abies balsamea* (L.) Mill.	15 - 30*
Eastern white pine *Pinus strobus* L.	5 - 10
Paper birch *Betula papyrifera* Marsh.	5 - 10
Eastern hemlock *Tsuga canadensis* (L.) Carr.	15 - 25
Northern white cedar *Thuja occidentalis* L.	5 - 10
Other	5 - 10

* Where widespread spruce budworm *Choristoneura fumiferana* (Clem.) infestation is present this is probably too high as a goal, but nevertheless realistic in terms of the effort required to achieve a much lower fir representation in the stand.

e. *Diameter-class distribution.* A balanced diameter class distribution is essential to the selection system. A stand that has or is approaching a balanced diameter distribution is a stand in which age classes cannot be readily recognized (Meyer et al. 1952). In balanced stands, each periodic harvest will include a greater volume in large, mature trees than in small, young trees. In selection forests, DeLiocourt (1898) observed that the numbers of trees in successive diameter classes form a geometric progression. When these are plotted on graph paper, they form an inverse J-shaped curve. If they are plotted on semilogarithmic paper, the plot should approximate a straight line.

With either method, the closer the actual data fit the ideal curve or line, the better the diameter distribution is balanced. The quotient "q", or ratio of the number of trees in a diameter class divided into the number of trees in the next smaller diameter class, should be about 1.3 or 1.4 for stands being managed for several products. Balanced distributions by 1-inch classes having a "q" of 1.4 for three operating intervals and for stands being managed for integrated products are given in Table 1.[1]

On many sites that support spruce-fir types, the maximum diameter of the largest trees at the end of an operating interval should not exceed 20 inches dbh. In selecting a maximum tree size both product objective and the potential of the site to produce large trees in a reasonable time must be considered.

d. *Stand density.* The average stand density (stand density midway through the operating interval) necessary for sustained yield of all products should be between 100 and 120 square feet of basal area per acre for trees in all diameter classes, depending on the length of the operating interval. At the start of an operating interval (immediately after a harvest) this ranges between 80 and 115 square feet of basal area per acre (Table 1).

[1] Traditionally, "q" is based on 2-inch diameter classes, especially when the largest trees being managed for exceed 30 inches dbh. A "q" of 1.4 by 1-inch classes equals a "q" of 1.96 by 2-inch classes.

STAND TREATMENTS UNDER THE SELECTION SYSTEM

The initial operations under the selection system are stand conditioning operations. These operations are designed to groom formerly neglected stands by removing poor-risk and poor-quality trees. These trees may comprise the bulk of the material removed initially, with the windfirmness of the residual stand the only constraint.

Windfirmness of a stand after harvest should be given priorty over all other stand characteristics. To minimize the danger of wind damage, limit timber stand improvement and harvest operations to 10 to 40 percent of total basal area on primary softwood sites—the poorly drained areas and the thin soils of upper slopes. Similar precautions are required on secondary softwood sites—the better drained deep soil areas—where 30 to 50 percent of basal area may be removed at any one time. The amount to remove in any operation will depend on specific site conditions (Frank and Bjorkbom 1973) and should be based on experience in a given area. When possible, maintain a basal area near the goals stated in Table 1.

Once the volume of poor-risk poor-quality trees is reduced to an acceptable level, stricter compliance with selection-system criteria is called for, and the controlling factor is the stand-density goal.

The proportion of the net periodic volume growth removed during an operation is governed by the amount of total basal area in the stand at the time of the harvest. If the postharvest stand-density goal cannot be met because of inadequate stocking, less than the total periodic growth should be removed. For a rapid buildup of growing stock in a stand, only one-half the net periodic growth should be removed in each operation until the density goal can be met. If the postharvest stand-density goal can be met initially, 100 percent or more of the periodic volume growth is harvested.

Once the amount of growing stock to be removed is determined, the harvest is distributed among size classes and species in order to meet the

Table 1.—Balanced diameter-class distributions ("q" = 1.4): theoretical stand stocking goals at the start of 5-, 10-, and 20-year operating intervals (expressed as number of trees per acre and square feet of basal area per acre).

Dbh Class	5-year Operating interval		10-year Operating interval		20-year Operating interval	
	Trees	Basal area	Trees	Basal area	Trees	Basal area
in.	*no.*	*ft²*	*no.*	*ft²*	*no.*	*ft²*
5	78	10.6	68	9.4	57	7.7
6	56	10.9	49	9.6	40	8.0
7	40	10.6	35	9.3	29	7.7
8	28	9.9	25	8.7	21	7.2
9	20	9.0	18	7.9	15	6.5
10	15	7.9	13	7.0	11	5.8
11	10	6.8	9	6.0	7	5.0
12	7	5.8	6	5.1	5	4.2
13	5	4.9	5	4.3	4	3.6
14	4	4.0	3	3.6	3	2.9
15	3	3.3	2	2.9	2	2.4
16	2	2.7	2	2.4	1	2.0
17	1	2.2	1	1.9	—	—
18	1	1.7	1	1.5	—	—
19	1	1.4	—	—	—	—
Total	271	91.7	237	79.6	195	63.0
1-4	774	23.3	683	20.5	565	17.0
Grand total	1045	115.0	920	100.0	760	80.0

treatment goals for these as closely as possible. Harvesting is a process of removing excesses to achieve the desired species composition and balanced diameter distribution.

In attempting to reach these treatment goals, thought must be given to (1) the proper distribution of residual trees, especially those being groomed as selected crop trees, (2) the environmental conditions necessary for the establishment of reproduction, and (3) the windfirmness of the residual stand.

Optimum growing space is essential for the rapid development of crop trees. For pole-sized white spruce, optimum growing space is created by releasing trees from their competitors on at least three sides (Frank 1973). In spruce-fir it is probably best to release trees when they are in the 4-inch dbh to 8-inch dbh classes. And under intensive management, even smaller trees should be released.

For the continuing development and establishment of new seedlings, openings larger than those created by the removal of individual trees may be required. The area around developing crop trees should be enlarged in successive operations.

Two of the more important steps are marking the stand to be harvested and seeing to it that loggers comply with the marking as closely as possible. In the early operations not all goals will be met simultaneously, and considerable judgment is required to achieve a balance among them. The reader is encouraged to review A Silvicultural Guide for Spruce-Fir in the Northeast (Frank and Bjorkbom 1973) for guidance in selecting and marking trees, developing tally sheets, and for additional information related to uneven-age silviculture.

THE TREATMENTS IN PRACTICE

On the Penobscot Experimental Forest we have been practicing various degrees of selection system silviculture and management using the basic profiles just outlined. Three intensities of the selection system, after 20 years under management, reached a point where early comparisons between intensities are possible. We also have data on an unregulated harvesting area and a woodland preserve for comparison.

Treatments are replicated twice, except for the woodland preserve, which is not replicated. All data are derived from 155 circular plots of 1/5-acre each, located either systematically or randomly. Treated areas average about 25 acres each.

Trees 4.5 inches dbh and larger are measured on the 1/5-acre plots; trees smaller than 4.5 inches dbh but at least 0.5 inch dbh are measured on circumscribed 1/20-acre plots; and trees smaller than 0.5 inch dbh are measured on three circular milacre plots systematically located on the circumference of each 1/20-acre plot. Sampling intensities are 13.0 percent, 3.3 percent, and 0.2 percent, respectively.

The selection system treatments

The intensity of the selection treatments we are applying is characterized by the frequency of stand entry, the minimum size-class of trees being treated, and the residual growing stock goals. We have both a 5-year operating interval and a 10-year operating interval under intensive management, and a 20-year operating interval under extensive management.

Under our intensive selection goals we mark trees down to the 1-inch diamter class for harvest or timber stand improvement. Our extensive selection treatment calls for marking trees in the 5-inch diameter class and larger only.

A more rapid buildup of growing stock is expected with the intensive treatments than with the extensive ones. In the former, up to 50 percent of net periodic growth is left to be added to the growing stock at each harvest until the desired stocking level is reached; in the latter, a maximum of 25 percent of net periodic growth is left.

Unregulated harvesting

Our unregulated harvesting area provides no control over harvesting practices. The loggers take the best and leave the rest. This treatment results in a heavy felling of merchantable trees and sometimes can approach a true clearcut. When all but a few trees are removed, the next stand entry may be delayed 40 to 65 or more years.

Woodland preserve

Our woodland preserve area is set aside to allow natural processes to control the development of the forest ecosystem. No harvesting operations or other treatments take place in this area.

RESULTS AND COMPARISONS

Results and treatment comparisons based on 20 years of observations (only 17 years in one treatment) must be read in the proper context. We emphasize that in most forest stands this is less than half of the time needed to produce either pulpwood-sized or sawlog-sized trees.

With these words of caution, we present the following results and comparisons for:

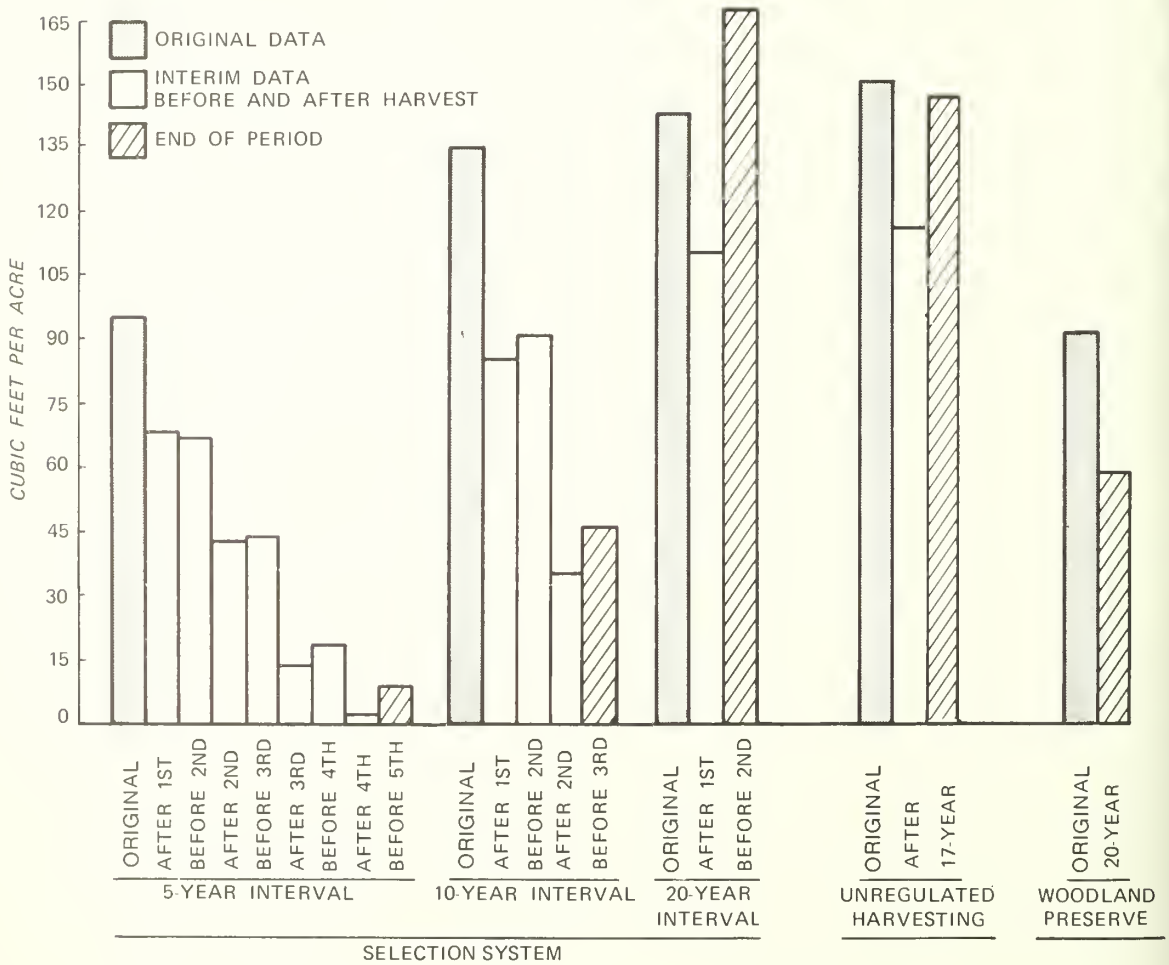
a. Stand quality
b. Species composition
c. Diameter-class distribution
d. Stand density
e. Growth

Stand quality

One measure of stand quality is the percentage of stand volume in cull trees. Our definition of a cull tree is a tree that contains less than 50 percent usable material. The cull and otherwise nonusable portions of merchantable trees are not included in the measure of stand quality. A major reduction of cull-tree volume occurred in the two intensive selection treatments; a moderate increase in the extensive selection treatments; practically no change for the unregulated method; and a moderate reduction due to natural mortality in the woodland preserve (Fig. 3).

We measured a 90 percent reduction in cull-tree volume in the intensive treatment with the 5-year operating interval. In this stand, subjected to four

Figure 3. Volume in cull trees by treatment and time period.



harvest and timber stand improvement operations, stand entries are twice and four time as frequent as those under the 10-year intensive selection treatment and the 20-year extensive selection treatment.

Cull-tree volume was reduced 65 percent under the intensive selection treatment with a 10-year operating interval; it increased 17 percent under extensive selection with a 20-year interval.

Cull-tree volume fluctuates with time in stands being managed by the selection system. Reductions in cull volume observed after each operation were usually followed by increases during the interval between stand entries (Fig. 3). Both the periodic rate of cull-tree volume accumulation and the periodic change are related to the length of the operating interval. More lengthy operating intervals tend to increase the rates of cull- tree volume accumulation between stand entries, because cull trees are allowed to accrue more volume.

These relationships for the initial 20 years of selection treatment are shown below (in cubic feet per acre):

Interval	*Annual cull-tree volume accumulation rate*	*Periodic cull-tree volume increase or decrease*
5-year	0.6	−87
10-year	0.9	−89
20-year	2.8	+24

At the end of the treatment period, cull-tree volumes in the selection system treatments were 0.6 percent, 2.5 percent, and 6.2 percent of growing stock for the 5-, 10-, and 20- year interval treatments, respectively.

With unregulated harvesting, cull-tree volume increased modestly from 8.1 percent to 10.6 percent of growing stock. Cull-tree volume accumulation was at an annual rate of 1.9 cubic feet per acre. The cull-tree volume at the end of the treatment period was 10.6 percent of growing stock, 3.4 times the average for the selection systems.

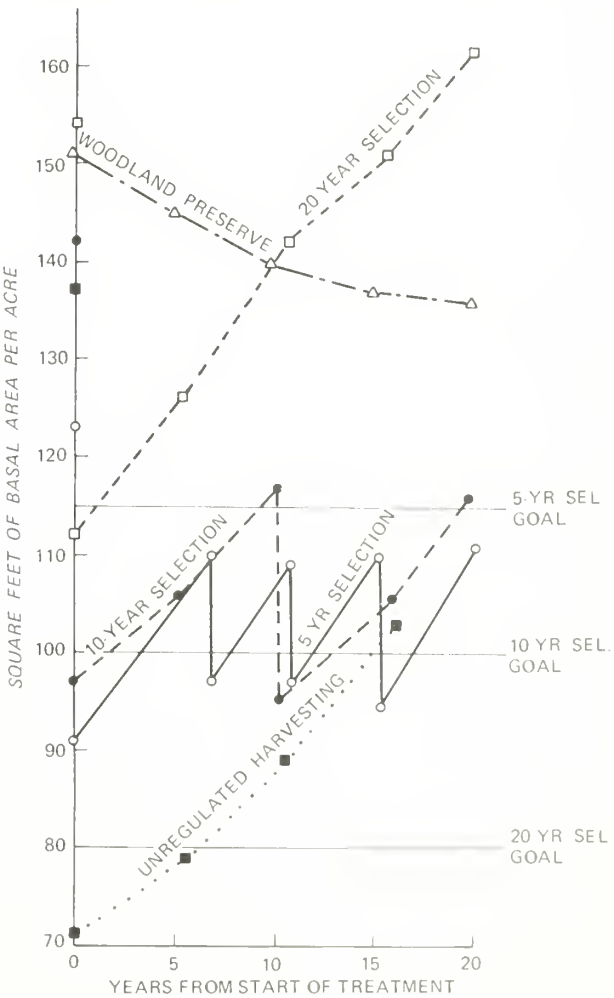
Surprisingly, cull-tree volume decreased from 4.0 to 2.4 percent of growing stock in the woodland preserve, apparently because of the high mortality rate of 52 cubic feet per acre per year—almost 6 times that observed in the selection areas and almost 3.5 times that observed in the unregulated area. Evidently cull trees were not persisting. Two-thirds of the mortality was in balsam fir.

Stand density

Densities of the selection system treatments were designed to be different at the start of an operating interval which is immediately after each harvest (Fig. 4). Theoretically they should be approximately equal at the end of each interval which is immediately before each harvest.

The density goal of the 20-year interval treatment was lowest; the goal for the 5-year interval the highest. However, these goals were not met because of variations in original basal areas, fear of excessive wind damage after logging, and continued removal of poor-risk trees to condition stands. Inconsistencies in controlling basal area

Figure 4. Actual and theoretical basal area densities by treatment at various times.



densities are being reduced and variations from goals will shortly be minimized (Fig. 4). And as more knowledge becomes available, the goals themselves may be changed. For instance, if adequate numbers of saplings fail to reach pole size, this may indicate overstocking and density goals might be reduced.

Species composition

The species composition goals given earlier are based primarily on the adaptability of the various species to environmental conditions fostered by the selection system and their ability to grow on a range of spruce-fir sites. On most spruce-fir sites, shade-tolerant species such as red spruce, balsam fir, and hemlock will increase in numbers in the understory soon after selection silviculture is initiated. Less shade-tolerant species, including paper birch and white pine, will decline in numbers. In fact, an early increase in regeneration of preferred species in the understory is no guarantee that they will be successfully established unless the necessary cultural practices are carried out periodically. It will take a long time to change the representation of species in the overstory.

How close we are to meeting these goals now and in the near future is reflected in the present composition of the sapling, pole, and sawtimber classes. How well we will fare over the long term, however, is indicated by trends in species composition, growth, and regeneration from which crop trees will eventually be chosen.

Species composition of regeneration. The tolerant spruces, primarily red and white spruce, increased in both numbers per acre (Table 2) and percent stocking (Table 3) under all treatments; in the woodland preserve, there was a decrease in percent stocking of spruce less than 6 inches tall. Percent stocking as a measure of the number of stocked milacres is an indicator of the distribution of regeneration throughout the area being sampled.

The largest increase in spruce seedlings taller than 6 inches occurred in the stands managed by the selection system. Spruces made up 11.1 percent of all seedlings at 19 years, compared with 7.4 percent at 9 to 10 years (Table 2). Perhaps of greater importance to future stand composition than number of seedlings is the increase in percent stocking of this size class. In the selection system stands, spruce stocking increased from an average of 16 percent 9 to 10 years after treatment to 42 percent after 19 years (Table 3).

Balsam fir is increasing in large numbers except where management is most intense—the 5-year interval selection treatment. This treatment registered the smallest gain, only 1,000 seedlings per acre during the past 10 years. Balsam fir had the highest stocking of any species.

Hemlock is responding in a manner very similar to spruce, but numerical increases are much larger. More prolific seeding habits, greater seed source, and greater shade tolerance account for these increases. Hemlock, though not as highly

Table 2. Status of regeneration: number of stems per acre 6 inches in height to 0.5 dbh by treatment at two periods of time after initial treatment.

Species	Treatment and number of years since initial treatment									
	Selection system						Unregulated (commercial clearcutting)		Woodland preserve	
	Intensive 5-yr interval		Intensive 10-yr interval		Extensive 20-yr interval					
	10 years	19 years	10 years	19 years	9 years	19 years	9 years	19 years	10 years	19 years
Spruce	430	1160	770	2500	160	730	370	640	150	1040
Balsam fir	2990	3990	4390	9290	900	2730	4600	6700	4150	12110
Hemlock	1770	5030	1070	5510	760	3830	1210	2190	150	340
Red maple	1300	1070	1070	1030	220	300	1310	1550	220	480
Paper birch	350	490	630	290	590	100	1790	360	70	740
Other species	400	780	420	460	230	200	1910	1030	560	810
Total	7240	12520	8350	19080	2860	7890	11190	12470	5300	15520

Table 3. Status of regeneration: percent stocking by treatment, by species, and by size class at two periods of time after initial treatment.

Species and size class	Treatment and number of years since initial treatment									
	Selection systems						Unregulated (commercial clearcutting)		Woodland preserve	
	Intensive 5-yr. interval		Intensive 10-yr interval		Extensive 20-yr interval					
	10 years	19 years	10 years	19 years	9 years	19 years	9 years	19 years	10 years	19 years
Spruce										
<6.0 in	59	65	64	79	66	86	32	36	63	59
>6.0 in	21	45	20	49	8	32	20	33	7	33
All	64	77	66	88	68	89	43	52	63	67
Balsam fir										
<6.0 in	85	81	97	90	94	93	89	86	100	100
>6.0 in	59	71	65	74	38	41	70	86	70	70
All	89	94	98	98	95	94	96	98	100	100
Hemlock										
<6.0 in	95	88	55	63	87	91	49	54	22	37
>6.0 in	49	62	25	46	12	47	31	36	15	22
All	95	93	57	72	87	91	54	61	33	48
Red maple										
<6.0 in	79	77	85	39	77	50	54	77	96	93
>6.0 in	26	30	30	33	9	14	39	41	7	26
All	83	82	87	58	77	59	65	84	96	100
Paper birch										
<6.0 in	27	23	30	16	24	6	27	17	37	59
>6.0 in	13	14	21	14	14	9	35	16	7	7
All	30	28	38	23	30	12	44	28	44	59
Other species										
<6.0 in	34	24	42	37	26	13	50	41	44	63
>6.0 in	18	26	16	20	5	10	32	36	22	33
All	40	38	49	49	27	21	61	57	44	74
All species										
<6.0 in	100	96	99	94	98	98	98	93	100	100
>6.0 in	81	85	81	82	53	61	85	90	70	78
All	100	99	100	99	98	98	100	99	100	100

favored as the spruces, is a species well adapted to our stand conditions.

Red maple (*Acer rubrum* L.), usually an unwanted species because of its poor quality and restricted markets, is being reduced numerically under selection silviculture. Our aim is not to eliminate it completely but to encourage only selected specimens. It should not be a future problem in our selection stands but is increasing in both the unregulated stands and the woodland preserve.

Other species present are cedar, white pine, aspen (*Populus tremuloides* Michx., and *P. grandidentata* Michx.), paper birch and gray birch (*Betula populifolia* Marsh). They will not be major components of selection stands. As seed-source trees of these species are removed from the overstory, the opportunity for establishing new regeneration is diminished. Also, the ability of these less tolerant species to grow into a dominant position is limited because of the continuous overstory present. The more open crown canopy of the unregulated stands enhances the persistence of intolerant species. Their retention and propagation in the woodland preserve is dependent upon a seed source in the overstory and upon conditions favorable for regeneration and ultimate establishment brought about by high mortality. White pine is and has been a very important component of the growing stock in the woodland preserve. Cedar is also represented in moderate numbers.

None of our treatments has resulted in a shortage of established regeneration (Table 2 and 3). For instance, after 19 years of management, the lowest percent stocking by species is restricted to the two treatments supporting the most basal area:

Spruce — 32 percent stocking, 20-year interval selection

Balsam fir — 41 percent stocking, 20-year interval selection

Hemlock — 22 percent stocking, woodland preserve

Red maple — 14 percent stocking, 20-year interval selection

Paper birch — 7 percent stocking, woodland preserve

Other species — 10 percent stocking, 20-year interval selection

Any species — 61 percent stocking, 20-year interval selection

In summary, observations of regeneration over a period of almost 20 years indicate that spruce-fir stands can be cultured to ultimately support favored species and that species composition goals can be met.

Species composition of saplings, poles, and *sawtimber.* It will be many years before the stands being managed under the selection system reach the species composition goals suggested for spruce-fir types. The time required to mold a stand to a desired species composition is related both to the intensity of management and to the differences between the composition goal and that of the original stand—the lower the intensity and the larger the deviation, the more time is required.

With the exception of the 10-year interval stands, where the goal has been reached primarily because of favorable species representation at the outset, the goals of the other selection treatments have not been reached. Both the 5-year and the 20-year interval stands supported a minor amount of spruce and fir and a large amount of hemlock (Table 4). However, if the present trend continues in these stands, the spruce-fir component will increase at the expense of all other species including hemlock. The hemlock component is expected to decrease slowly under all levels of management,

Table 4. Status of trees 0.5 inches dbh and larger: percentage of basal area by species at various times for each treatment.

Time	Species					
	Spruce	Balsam fir	Hemlock	Red maple	Paper birch	Other species[a]
			SELECTION, 5-YEAR INTERVAL			
Original stand	14	11	40	11	5	19
After 1st harvest	17	12	40	7	6	18
Before 5th harvest	22	17	44	5	4	8
Selection system goal	35-65	15-30	15-25	5-10	5-10	10-20
			SELECTION, 10-YEAR INTERVAL			
Original stand	20	36	16	8	3	17
After 1st harvest	27	36	14	7	2	14
Before 3rd harvest	34	28	16	10	3	9
Selection system goal	35-65	15-30	15-25	5-10	5-10	10-20
			SELECTION, 20-YEAR INTERVAL			
Original stand	15	16	47	3	1	18
After 1st harvest	18	17	43	2	1	19
Before 2nd harvest	20	18	45	3	1	13
Selection system goal	35-65	15-30	15-25	5-10	5-10	10-20
			UNREGULATED HARVESTING			
Original stand	17	29	19	12	4	19
After 1st harvest	7	29	15	17	4	28
17th year measurement	10	24	18	20	5	23
			WOODLAND PRESERVE			
Original stand	13	37	13	7	2	28
20th year measurement	14	18	18	14	3	33

[a] Mostly northern white cedar, eastern white pine, and other hardwoods.

both with the removal of all low quality, poor risk trees and with the entrenchment of a stronger component of intensively favored spruce.

As expected, unregulated harvesting reduced the spruce-fir component and correspondingly increased hardwoods. These results would have been more pronounced if a higher proportion of the stand had been harvested.

Except for the large reduction in balsam fir, the composition of the woodland preserve remained relatively stable. The reduction in fir was accompanied by gains in hemlock, red maple, and white pine. A further reduction in the relatively short-lived balsam fir component is expected in the future.

Diameter-class distribution

The number of years required to approach the goals shown in Table 5 depends on the original stand conditions and the length of the operating interval. Experience has demonstrated that two or three conditioning operations at the scheduled intervals are needed to achieve semblance of order in a formerly disordered stand.

Early trends in our stands under selection silviculture show a rapid reduction in numbers of trees in the 1- to 4-inch dbh class (Table 5 and Fig. 5). However, except for the two smallest classes in the 5-year interval treatment, all other diameter classes in selection treatments are close to their goals or show surpluses from which the next removals will be made. Diameter distributions are expected to remain essentially balanced after this operation is completed.

The relatively dense canopy of the woodland preserve is retarding the development of seedlings into the sapling class. This may not continue, however, because the high mortality in this treatment has created openings suitable for sapling development. Almost 60 years after the last harvest in this stand, the number of saplings is 300 per acre and the total number of trees in all size classes is only 600 per acre. No other treatment has so few trees.

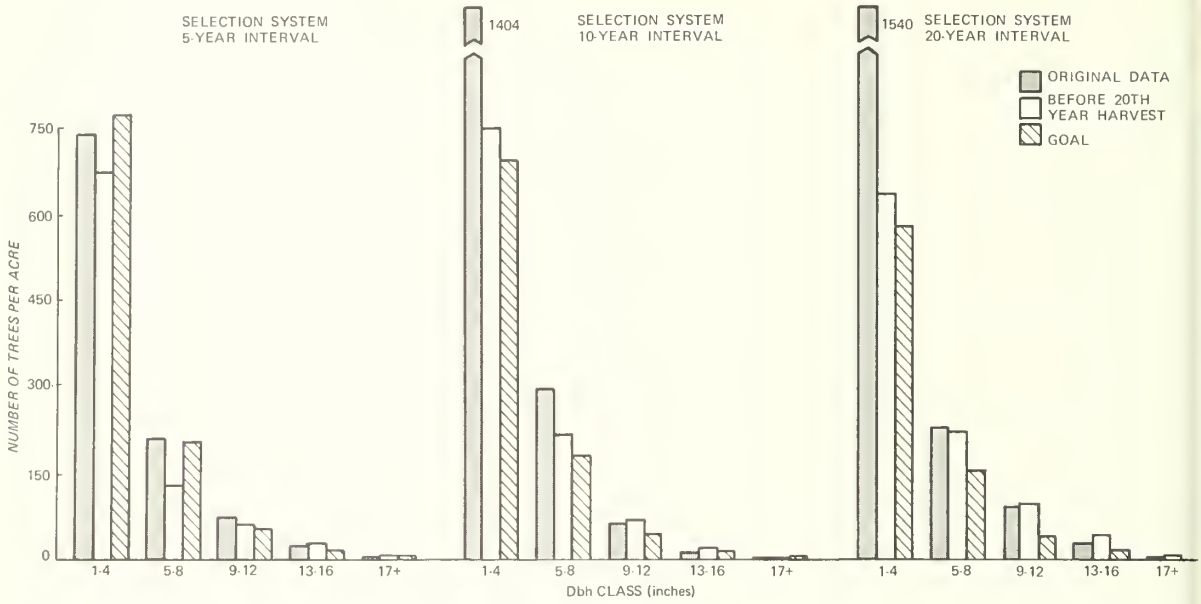
Table 5. Status of trees 0.5 inches dbh and larger: number of trees per acre by 4-inch diameter classes at various times for each treatment.

Time	Size class (dbh in inches)					Total
	Saplings (1-4)	Poles (5-8)	Small sawtimber (9-12)	Medium sawtimber (13-16)	Large sawtimber (17+)	
			SELECTION, 5-YEAR INTERVAL			
Original stand	*734*[a]	207	72	19	*2*	*1034*
After 1st harvest	*624*	*160*	56	*13*	*1*	*854*
Before 5th harvest	*668*	*126*	61	23	3	*881*
Goal after harvest	773	202	53	14	3	1045
			SELECTION, 10-YEAR INTERVAL			
Original stand	1404	285	60	*9*	*1*	1759
After 1st harvest	1016	223	*36*	*4*	[b]	1279
Before 3rd harvest	730	211	64	14	*1*	1020
Goal after harvest	683	177	46	12	2	920
			SELECTION, 20-YEAR INTERVAL			
Original stand	1540	221	88	22	2	1873
After 1st harvest	1200	193	68	11	[b]	1472
Before 2nd harvest	625	217	90	35	3	970
Goal after harvest	565	147	38	10	0	760
			UNREGULATED HARVESTING			
Original stand	999	287	60	10	2	1358
After 1st harvest	693	186	20	2	1	902
17th year measurement	1054	228	45	6	1	1334
			WOODLAND PRESERVE			
Original stand	858	310	64	16	4	1252
20th year measurement	299	200	70	23	9	601

[a] Values in italics are below goals based on q = 1.4

[b] Less than 0.5 trees per acre

Figure 5. Diameter-class distribution by number of trees per acre by treatment at two periods of time and by goal.



Periodic annual growth

The components of growth include net growth, mortality, ingrowth, accretion, and gross growth. These terms are:

Net growth. The net change in volume between two inventories (ingrowth + accretion − mortality). Also called net increase and production.

Mortality. Trees that died during the measurement period, excluding ingrowth trees that died.

Ingrowth. Trees that grew larger than the threshold size (4.5 inches dbh) between inventories.

Accretion. Increase in the volume of all trees present initially and still present at the end of the period (survivor growth).

Gross growth. Total volume produced by all trees during the period (net growth + mortality).

Net growth and mortality. Growth data are for all trees 4.5 inches dbh and larger. Volume in these trees is that of a bark-free bole from a 1-foot-high stump to a 4-inch-diameter top.

Periodic annual net growth varied greatly between the selection treatments and the unregulated harvesting and woodland preserve—from a low of 9 cubic feet per acre per year in the woodland preserve to a high of 53 to 60 cubic feet per acre per year in the selection treatments. The unregulated area grew at a net rate of 36 cubic feet per acre per year (Table 6 and Fig. 6).

Mortality ranged from 5 to 14 cubic feet per acre per year in the selection treatments; it was 15 cubic feet per acre per year in the unregulated treatment and 52 cubic feet per acre per year in the woodland preserve, where almost two-thirds of the mortality was balsam fir. The loss of this species resulted in an average drain from growing stock of 16.5 cubic feet per acre per year (Table 6 and Fig. 6).

Harvested volumes and number of harvests for each treatment are given below. They do not include volumes to be removed during the 20th year because these data are not yet available.

Treatment	*Number of harvests*	*Volume removed* ft^3*/acre*
Selection system		
5-yr interval	4	1260
10-yr interval	2	1100
20-yr interval	1	700
Unregulated	1	1050
Woodland preserve	0	0

Table 6. Distribution of periodic annual growth by species, treatment, and growth component (in cubic feet per acre).

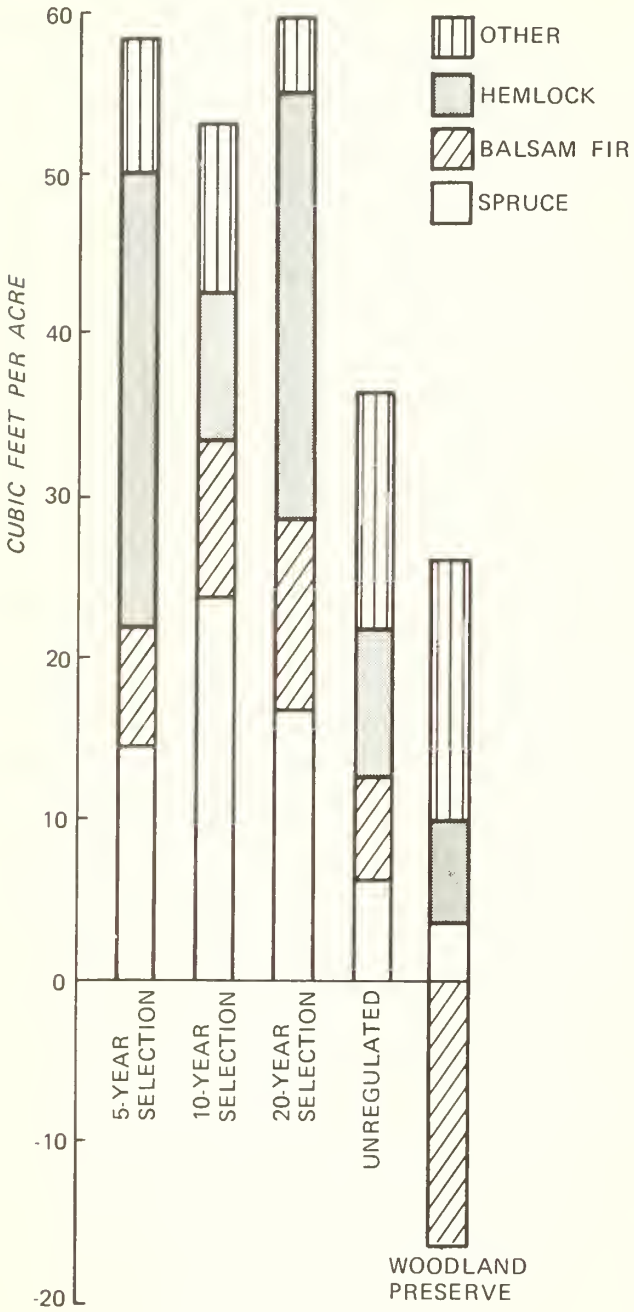
Species	Treatment	Growth Component				
		Ingrowth	Accretion	Gross growth	Mortality	Net growth
Balsam fir	Intensive selection 5-yr	4.6	4.3	8.9	1.7	7.2
	Intensive selection 10-yr	7.5	11.9	19.4	9.7	9.7
	Extensive selection 20-yr	5.6	7.6	13.2	2.1	11.1
	Unregulated	7.3	7.9	15.2	8.8	6.7
	Woodland preserve	6.5	11.0	17.5	34.0	-16.5
Spruce	Intensive selection 5-yr	0.7	14.8	15.5	1.1	14.4
	Intensive selection 10-yr	2.0	23.6	25.6	2.1	23.5
	Extensive selection 20-yr	1.1	17.0	18.1	1.0	17.1
	Unregulated	1.0	5.7	6.7	.6	6.1
	Woodland preserve	.7	8.4	9.1	5.4	3.7
Hemlock	Intensive selection 5-yr	2.0	26.9	28.9	.5	28.4
	Intensive selection 10-yr	.7	8.7	9.4	.3	9.1
	Extensive selection 20-yr	1.2	27.6	28.8	2.1	26.7
	Unregulated	1.6	8.9	10.5	1.5	9.0
	Woodland preserve	.7	5.5	6.2	.0	6.2
Other softwood	Intensive selection 5-yr	.8	3.3	4.1	1.4	2.7
	Intensive selection 10-yr	.7	3.4	4.1	.9	3.2
	Extensive selection 20-yr	.7	2.6	3.3	1.2	2.1
	Unregulated	1.0	5.3	6.3	1.5	4.8
	Woodland preserve	.1	16.8	16.9	11.2	5.7
Red maple	Intensive selection 5-yr	.7	2.7	3.4	.1	3.3
	Intensive selection 10-yr	1.7	3.8	5.5	.2	5.3
	Extensive selection 20-yr	.7	1.4	2.1	.2	1.9
	Unregulated	2.6	5.8	8.4	1.2	7.2
	Woodland preserve	2.6	5.9	8.5	.4	8.1
Paper birch	Intensive selection 5-yr	.1	1.8	1.9	.1	1.8
	Intensive selection 10-yr	.3	1.7	2.0	[a]	2.0
	Extensive selection 20-yr	.2	.7	.9	.3	.6
	Unregulated	.5	2.0	2.5	.3	2.2
	Woodland preserve	[a]	1.4	1.4	.1	1.3
Other hardwood	Intensive selection 5-yr	.3	.7	1.0	.3	.7
	Intensive selection 10-yr	.2	.5	.7	.4	.3
	Extensive selection 20-yr	.1	.1	.2	.2	.1
	Unregulated	.5	1.0	1.5	.7	.7
	Woodland preserve	.0	2.2	2.2	1.3	.9
Total	Intensive selection 5-yr	9.1	54.5	63.6	5.2	58.4
	Intensive selection 10-yr	13.2	53.7	66.9	13.6	53.3
	Extensive selection 20-yr	9.7	57.0	66.7	7.1	59.6
	Unregulated	14.4	36.7	51.1	14.7	36.4
	Woodland preserve	10.7	51.1	61.8	52.4	9.4

[a] Less than 0.05 cubic feet

The situation in the unregulated stands and woodland preserve are strikingly different. Unregulated commercial clearcutting reduced stand density to an understocked condition. Basal area in merchantable-sized trees was only 50 square feet per acre; total basal area was 71 square feet per acre. Increasing periodic annual net growth figures of 29, 36, and 42 cubic feet per acre suggest that acceptable growing stock is developing, despite the lack of silvicultural input. The stand has a current stocking of 109 square feet per acre.

The woodland preserve supported 151 square feet of basal area per acre at the start of the study. Natural attrition has reduced this to 136 square

Figure 6. Periodic average annual net growth by species and treatment.



feet per acre. Both these levels represent overstocking, as is shown in the high average annual mortality rate.

The loss of fir on the woodland preserve reduced this species to 18 percent of total stand basal area after 20 years, from 37 percent at the start of observations. The loss of fir and other species amounted to 875 cubic feet per acre over and above that lost on the selection system areas during the 20-year observation period.

Ingrowth. Ingrowth data attest to the aggressiveness and persistence of balsam fir. Regardless of treatment, balsam fir ingrowth amounted to between 50 and 60 percent of total ingrowth. No other species approached this level. Spruce ranged between 7 and 15 percent; hemlock, between 5 and 22 percent; and red maple, between 7 and 24 percent (Table 6). Ingrowth of balsam fir is expected to decline in the 5- and 10-year selection treatments because fir trees are periodically removed from the overstory, reducing seeding potential. However, fir will remain a major contributor of ingrowth in the unregulated stands because fir growing stock is continuously replenished. And for the immediate future, fir will dominate ingrowth in the woodland preserve because the openings created by fir mortality regenerate to fir.

Increases of spruce are possible in the selection system being tested as spruce overstory trees become more important in the species mix. Removals of less desirable species and cultural treatments favoring spruce make this possible.

Accretion and gross growth. Accretion is perhaps one of the best indexes of success or failure of a treatment to provide optimum growing conditions for individual trees. It is also the component of growth most significantly affected by abnormal weather patterns. For instance, an extended drought usually results in a slowdown in individual tree growth.

The stands managed by the selection system have maintained the highest annual accretion—54 to 57 cubic feet per acre. Added to relatively high ingrowth, this results in high gross growth. For the selection system at the intensities under investigation, annual gross growth had a narrow range of from 64 to 67 cubic feet per acre (Table 6).

The accretion rate in the woodland preserve was also high; 51 cubic feet per acre per year. Accre-

tion is not expected to vary with slight increases in stand density. And average stand density in the preserve was slightly higher than in the 20-year interval selection treatment—144 square feet per acre compared to 137 square feet per acre when beginning and current basal areas are averaged. With the addition of ingrowth, gross growth averaged 62 cubic feet per acre during the period.

For the area subjected to the unregulated commercial clearcut, accretion was at an annual rate of 37 cubic feet per acre. As stand density increases and the stand again becomes fully stocked, accretion is expected to increase. Gross growth was 51 cubic feet per acre per year.

In both the unregulated stands and the woodland preserve where spruce is not being managed for, the accretion rate of fir exceeds that of spruce. In the selection treatments, spruce is favored and its accretion rate is more than twice that of balsam fir (Table 6). Hemlock, a strong contender for site occupancy, has a slightly higher accretion than spruce.

DISCUSSION AND CONCLUSIONS

Except in the most degenerate forest stands, the concepts of selection system silviculture can be put into practice in most spruce-fir types. The goals and procedures we have set forth are believed to be both attainable and practical.

We will not attempt to base a long-range forecast from our silvicultural systems on only 20 years of records. However, our initial comparisons between the selection systems, a commercial clearcut, and a woodland preserve reflect long-term trends. How predictive these trends are must be evaluated in the future.

Our findings indicate that a forest will respond to the intensification of cultural practices. Frequent and regular periodic operations, employing proper silvicultural concepts, will:

- improve stand quality by removing poor-risk trees,
- eventually change species composition to the degree made possible by the silvical characteristics of the species and the silvicultural system being used,
- result in a diameter-class distribution approaching the stated goal,
- control stand density and maintain it at the desired level, and
- increase the yield of a variety of forest products by harvesting trees that are likely to die and increasing the growth of residual trees.

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Abstract

Questionnaires for evaluating what people expect from environmental camps and what they learn while there have been developed and applied at the Pocono Environmental Education Center, Dingman's Ferry, Penna. Nine questionnaires for various ages and types of users are presented. The results can be used by camp administrators and educators to evaluate their own programs and teaching methods.

INTRODUCTION

WHAT DO PEOPLE EXPECT to get from environmental camps? What do they actually go away with? How can the quality of user experiences be improved? These are questions that every camp director needs to answer if he expects to provide meaningful and rewarding encounters. Techniques designed to answer such questions were recently developed and used at the Pocono Environmental Education Center (PEEC). The study was a cooperative venture between PEEC, New York University, and the U. S. Forest Service. Dr. Fred Geis was the principal investigator.

Results are presented here in the hope that other camp administrators and educators can use these techniques to evaluate their own programs and teaching methods to better satisfy the needs of their clientele.

WHAT IS PEEC?

PEEC is a year-round base of operations for conferences, short-term institutes and workshops. Keystone Junior College of LaPlume, Pennsylvania, and the National Park Service cooperate in providing housing, study facilities, and program assistance at the camp for students (elementary through college) and virtually any other interested groups. The center is located in northeastern Pennsylvania within the Delaware Water Gap National Recreation Area. The majority of PEEC users come from metropolitan areas like New York City and Philadelphia. They represent a wide variety of backgrounds, ages, incomes and interests. Most first-time visitors have at least one thing in common: They know very little about the environment.

STUDY RESULTS

Nine questionnaires designed to measure the attitudes and awareness of environmental camp users were developed, tested, refined, and used at PEEC during 1976 and 1977. Key findings of that research, including summaries of user responses to questionnaires, are presented here.

Precamp attitudes of school groups

Data were collected from 12 groups, including 153 school children, ages 10 to 16. Results show that virtually all were looking forward to their visit to PEEC (Fig. 1). In fact, comparison of these data with group leader responses (Figs. 4 and 5) indicates that the kids were more confident and secure about the trip than their leaders.

Figure 1.—PRECAMP ATTITUDES OF SCHOOL GROUPS

Directions: (To be read to the students)

Think about each question and then answer it by circling *Yes* or *No* next to the question. Answer each question even when you decide you are not positively sure whether the answer is yes or no. When you are not sure just decide which is closest to what you think. (Then read each question to students and have them respond, if you feel they will have trouble on their own.)

Questions:	*Responses (in percent)*	
	Yes	*No*
1. Have you talked to anyone who has been to PEEC?	94	6
2. Are you happy to be going to PEEC?	99	1
3. Are you worried about any part of your trip?	2	98
4. Have you ever taken hikes in the country or in the woods?	99	1
5. Do you feel that you can learn more about nature at PEEC then where you usually meet?	99	1
6. Do you feel that you will have more free time at PEEC than where you usually meet?	52	48
7. Are your parents worried about sending you to PEEC?	2	98
8. Do you feel that you will miss anything by being away from where you usually meet for 3 or more days?	4	96
9. Do you feel that you know enough about what will take place at PEEC?	61	39
10. Did you have a chance to help in planning what you will do at PEEC?	35	65
11. Circle yes for all the places you have visited:		
Museum	65	35
Park or Nature Trail	85	15
Seashore or Beach	30	70
Zoo	60	40
Bird Sanctuary	25	75

Postcamp attitudes of school groups

The sample consisted of 324 urban children from 15 groups and 1,056 suburban and rural children from 27 groups. Ages ranged from 9 to 16 years. Rural and suburban users seemed happier or more positive about PEEC than urban users in almost all areas except food (Fig 2). PEEC's meals led the list with urban kids and even carried over into an enjoyment for doing kitchen chores. The ASE's (Action Socialization Experiences—a series of difficult tasks designed to encourage group cooperation), hikes and swimming were given high ratings by all groups but were also just as frequently cited as negative experiences. Interview data indicated that this reaction was due primarily to the level of stress or effort involved. Those in adequate physical shape to participate fully in the activities enjoyed them. Those less well equipped or prepared did not enjoy them as much.

Figure 2.—POSTCAMP ATTITUDES OF SCHOOL GROUPS

Directions: (To be read to the students)

Answer each question by circling *Yes* or *No* next to the question. If you are not positively sure whether the answer is yes or no, decide which is closest to what you think. (Then read each question to students and have them respond, if you feel they will have trouble on their own.)

Questions:	*Responses (in percent)*					
	Urban users			*Suburban and rural users*		
	Yes	*No*	*NA*	*Yes*	*No*	*NA*
1. Do you feel that being at PEEC was better than:						
a) A one-day field trip?	74	19	7	90	7	3
b) Visiting with your relatives out of town?	43	48	9	70	26	4
c) The same amount of time at a summer overnight camp or scout camp?	69	24	7	69	26	5
2. Which things did you enjoy doing at PEEC:						
a) Studying science in the field?	47	39	14	58	37	5
b) Studying other school subjects in the field?	44	44	12	45	41	14
c) Getting to know your classmates better?	72	11	17	82	6	12
d) Getting to know your teachers better?	72	18	10	77	20	3
e) Doing kitchen chores at PEEC?	56	33	11	21	70	9
f) Learning the rules of how to live together	16	77	7	70	27	3
3. Did the program at PEEC turn out as you had originally expected?	50	45	5	44	50	6
4. Do you feel that the size of the group was good for this trip?	83	16	1	88	11	1
5. Do you feel that some of your teachers who were with you have gotten to know you better?	82	16	2	83	14	3
6. Have you made any new friends among your classmates while at PEEC?	82	17	1	71	27	2
7. Do you feel that living in a cabin with other students was good?	92	7	1	91	8	1
8. Would you have liked to have had more time to do school work during the trip?	15	85	—	14	83	3
9. Do you feel that the sleeping arrangements were good?	86	13	1	86	12	2
10. Do you feel that the meals were good?	95	4	1	90	8	2
11. Do you feel this trip should be shorter in length?	5	93	2	4	94	2
12. Would you like to go to PEEC again?	97	3	—	95	4	1
13. Do you think you learned a lot at PEEC?	95	4	1	88	10	2

For students over the 5th grade:

Questions:	*—Most frequent responses—* *Urban users*	*Suburban and rural users*
14. What PEEC activity did you learn the most from?	ASE's[1] Bird walk Hikes Nature crafts Swimming	Stream & pond study Fossils Compass work Dancing Survival
15. What impressed you most about PEEC?	Braille trail Hiking Swimming Cabins Food	Hikes ASE's Cabins Braille trail Snake show Swimming
16. What activity did you enjoy the least?	ASE's Bird walk Films Hiking Nature crafts Sports Swimming Arts and crafts Soil study	Forestry Compass work Plot study Ecology Eating Discovering PEEC Arts and crafts Hikes Films Pond study

[1] Action Socialization Experiences—a series of difficult tasks designed to encourage group cooperation.

Environmental awareness test

Data were obtained from eight groups, all of urban children, a total sample of 183. Results indicate childrens' lack of historical perspective regarding population growth and land development and reveal the dependence that specialization imposes (Fig 3).

Figure 3.—ENVIRONMENTAL AWARENESS TEST

Directions:

Circle the answer you feel is correct. If you are not sure, circle the answer which is closest to what you think is right.

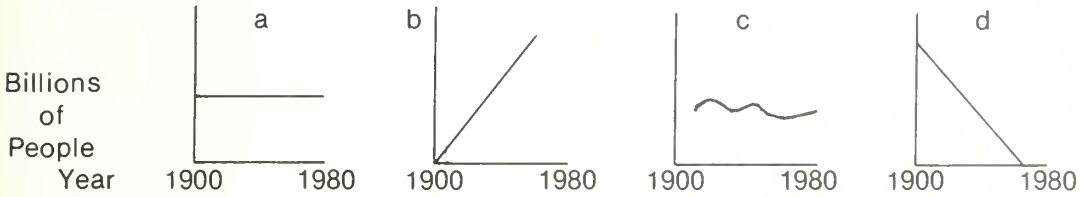
Questions:

Responses

(Numbers indicate percent of responses to that question.
* indicates correct response.)

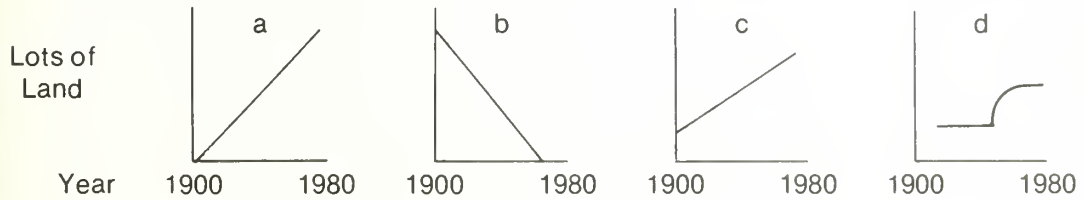
1. The environment is:
   a) Woods and lakes — 32
   b) Cities and factories — 8
   c) Pollution — 6
   d) All our surroundings — 54*

2. Which drawing best shows what is happening to the number of people in the world?



   a) 16
   b) 26*
   c) 39
   d) 19

3. Which drawing best shows what is happening to the amount of land for farms and forests?



   a) 19
   b) 31*
   c) 14
   d) 36

4. Most people live in cities because:
   a) Woods are dangerous with wild animals — 19
   b) There are more jobs in cities — 70*
   c) It is cold and lonely in the country — 4
   d) They like movies and music — 7

5. When lots of people live close together like in cities:
   a) It is easier to feed them and clean the garbage up — 9
   b) You can have better schools and stores — 28
   c) It is better because you keep the pollution all in one place — 18
   d) It is important to keep things clean because disease would spread easily — 45*

6. The reason the woods at PEEC are cleaner than New York City parks is:
   a) They have lots of people cleaning up — 15
   b) Country air is cleaner — 18
   c) People who visit PEEC are more careful not to pollute while they are there — 61*
   d) Wild animals eat the garbage — 7

7.	Before people came, the land New York City is on looked:	
	a) Kind of like an empty lot does	8
	b) Sort of like Central Park does	5
	c) Sort of like the woods at PEEC	40*
	d) Nothing was there until they built the city	47
8.	New York City's water comes:	
	a) From pipes	25
	b) From the ground	18
	c) From the Hudson River	10
	d) From lakes and rivers far away from the city	47*
9.	New York City's food comes:	
	a) From stores	10
	b) Only from farms in New Jersey	2
	c) Only from farms in California	0
	d) From farms all over the world	88*
10.	If farmers stopped working, city people would:	
	a) Have to eat canned and frozen food	10
	b) Probably starve to death	20*
	c) Have to eat artificial food	10
	d) Have to grow their own food	60
11.	In terms of pollution you can say that:	
	a) Both children and adults cause pollution	76*
	b) Children are against pollution but adults don't care	7
	c) Adults are against pollution but children don't care	9
	d) Only adults cause pollution	8
12.	The hardest part of having a clean environment is:	
	a) Getting everyone to cooperate	75*
	b) Having scientists find solutions	9
	c) Deciding which buildings to tear down	7
	d) Getting factories to be clean	9
13.	Most people don't keep the environment clean because:	
	a) They don't know how	7
	b) They don't care	64
	c) They aren't responsible for the mess	18
	d) It costs them time and money	11*
14.	The most important reason for having a clean environment is:	
	a) It looks much nicer	20
	b) We need it for our health	50*
	c) We need it for wild animals and trees	14
	c) We wouldn't have to spend so much money	16

Precamp attitudes of group leaders

The sample consisted of 14 groups with a total of 41 leaders. Most listed personal, social, and leadership development as prime reasons for coming to PEEC (Fig. 4). Features of greatest interest were hiking and other outdoor activities.

Figure 4.—PRECAMP ATTITUDES OF GROUP LEADERS

		Most frequent responses
1.	Why did you select PEEC for your group?	Low cost, pleasant facilities, environmental science theme, location, helpful staff, type of programs.
2.	What activities, facilities, or services at PEEC are of greatest interest to you?	Hiking and other outdoor activities.
3.	If you had only one goal you could fulfill at PEEC, what would it be?	80% listed personal, social, or leadership development, the rest listed learning about the environment and fun.
4.	Do you feel you can achieve your goals for your group better at PEEC than where you generally meet? Why?	Yes, because of price and opportunities for group work.
5.	How many people are involved in planning your PEEC experience?	Average 4.5
6.	Do you feel that you know enough about PEEC to plan your experience? If not, why not?	Yes, although some were confused about timing and nature of some activities.
7.	Are you planning to utilize any members of the PEEC staff in planning your PEEC experience?	Most said yes—less than 10% wanted to be left on their own.
8.	How can PEEC be of help to you between now and the time your group comes to PEEC?	Want to know more about resources at PEEC. Provide a list of activities related to seasons.
9.	In terms of pre-PEEC preparation do you feel:	
	a) You and the other leaders are ready?	95% Yes
	b) The participants are ready?	100% Yes

Evaluation of preparation sessions by group leaders

Preparation sessions give group leaders a chance to learn about the facility and its programs. Data were collected from six groups with 102 individuals responding. All data were obtained from the urban groups as they were the only groups that had large organized leader preparation sessions at PEEC. Most all group leaders felt the preparation sessions were worthwhile (Fig. 5). They were most apprehensive about being able to coordinate all activities in the time allowed.

Figure 5—EVALUATION OF PREPARATION SESSIONS BY GROUP LEADERS

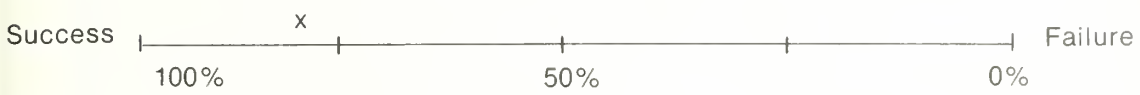
Questions:	*Responses (in percent)* Yes	No
1. Do you feel that the activities at PEEC were well organized?	85	15
2. Do you feel that the time at PEEC in preparation for your group's trip was enough?	76	24
3. Was the time you spent at PEEC generally worthwhile?	95	5
4. Were the orientation activities organized to make good use of your time?	83	17
5. Did the orientation sessions provide you with the information you need?	64	36
6. Do you feel prepared to bring your group to PEEC?	69	31
7. Do you feel PEEC is prepared for your group?	87	13
8. Do you feel bringing your group to PEEC will be worth the work and expense?	91	9
9. What changes would you recommend in the preparatory program you participated in at PEEC?	More material presented prior to PEEC, more teacher input, more free time, better planning for evening activities with kids.	
10. What activity do you feel was most worthwhile for you?	Hikes, ASE's, seeing PEEC facilities.	
11. What did you enjoy most during your stay at PEEC?	Social hour, being outdoors.	
12. What are your greatest apprehensions about bringing your group to PEEC?	That we won't be able to coordinate all things in the time we have, kids will go wild.	
13. In what aspects of the PEEC programs do you feel least adequate?	Knowledge of nature activities, managing kids outdoors.	
14. In what program areas do you feel strongest?	Nature arts and crafts, Braille trail, free time.	
15. How can PEEC be of help to you between now and the time your group comes to PEEC?	Better informative material on hikes, ASE's, and nature activities; help divide kids up and help lead activities.	

Postcamp reactions of group leaders

Twenty-four group leaders were interviewed. Of all features at PEEC, trail activities were their overwhelming favorite (Fig. 6). Some leaders complained about how the weather interfered with their program. There was a need for foul-weather activities.

Figure 6.—POSTCAMP REACTIONS OF GROUP LEADERS

1. How successful would you rate your group's trip to PEEC? (x indicates average)



2. To what extent was the success or failure attributable to factors within PEEC's control, such as facilities or activities?

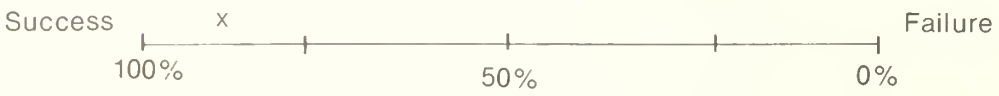
3.	What aspect(s) of PEEC was most useful to your group's activities?	
4.	What aspect(s) of PEEC was mentioned most often as fun or interesting?	Trails, swimming pool, ASE's, astronomy, food
5.	What aspect(s) of PEEC was mentioned as a negative influence?	Nothing, food, non-PEEC factors such as weather
6.	If PEEC had $50,000 to invest in facilities or programs, what would you advise them to do with the money?	Expand trails, trail guides, and camping facilities; expand structured programming and nature study activities; increase staff, build gym, improve food, upgrade cabins; maintenance; subsidize rates.

Postcamp attitudes of adult participants

Data came from 12 groups with a total sample of 263 individuals. Most adults rated their trip to PEEC a success (Fig. 7). Their favorite activities were hiking and swimming. There were some complaints, mainly concerning cabin maintenance.

Figure 7.—POSTCAMP ATTITUDES OF ADULT PARTICIPANTS

1. How would you rate your activities at PEEC? (x indicates average)



2. What did you most enjoy about PEEC?	More than 50% mentioned hiking trails, 35% mentioned swimming pool, 15% mentioned the surroundings and nature.
3. What aspect of PEEC caused the most problems for you?	25% mentioned problems with cabins (heat, plumbing, beds), 10% mentioned lack of alternate rainy weather activities.
4. If you were going to recommend one change or addition to PEEC, what would it be?	20% said improve cabin maintenance, 20% said more evening and indoor activities, 15% said more volleyball areas, 10% said to open the store longer and add more stock.

Postcamp attitudes of college groups

This sample came from two groups with 58 respondents. The college students have had some environmental education (Fig 8). They weren't sure what to expect from PEEC but were looking forward to the experience.

Figure 8.—PRECAMP ATTITUDES OF COLLEGE GROUPS

Questions:	*Responses (in percent)* Yes	No
1. Have you spoken to anyone who has already been to PEEC?	100	—
2. Have you participated in courses which have involved field study?	93	7
3. Have you ever taken hikes in the country or in the woods?	100	—
4. Do you feel that you can learn more about nature at PEEC than where your class usually meets?	83	17
5. Do you feel that you will experience more recreational activities at PEEC than at school?	95	5
6. Do you feel that you know enough about what will take place at PEEC?	49	51
7. Did you have a chance to help in the planning of the activities that you will experience at PEEC?	53	47
8. Are you looking forward to your PEEC experience?	95	5

Precamp attitudes of college groups

Respondents totaled 183 persons from eight groups. College students seemed to be favorably impressed with their PEEC trip (Fig 9). Prime benefits included getting to know their classmates and teachers better in a group living and learning experience.

Figure 9.—POSTCAMP ATTITUDES OF COLLEGE GROUPS

Questions:	*Responses (in percent)*	
	Yes	*No*
1. Do you consider that the PEEC experience was generally better than:		
a) A series of field trips.	97	3
b) A laboratory learning experience	99	1
c) A textbook learning experience	99	1
2. Do you feel that the major benefits to you during this program include:		
a) Studying science in the field	48	52
b) Studying any school subject in the field	65	35
c) Getting to know your classmates better	91	9
d) Getting to know your teacher better	86	14
e) Doing dining hall chores at PEEC	23	77
3. Did the program at PEEC turn out as you had originally expected?	52	48
4. Do you feel the size of the group was good for this experience?	98	2
5. Do you feel the student-instructor interaction at PEEC is different from that at school?	91	9
6. Have you made any new friends among your classmates while at PEEC?	97	3
7. Do you feel that the cooperation in group living by the students was good?	98	2
8. Would you like to have had more time to study independently while at PEEC?	56	44
9. Would you like to go to PEEC again for a similar experience?	100	—
10. Do you consider that your experience at PEEC was generally worthwhile?	100	—
11. Do you feel that the sleeping arrangements were?	Poor—0% Satisfactory—25% Good—46% Excellent—29%	
12. Do you feel the meals were?	Poor—8% Satisfactory—25% Good—35% Excellent—32%	
13. Do you feel that the length of your stay at PEEC was:	Too short—58% Just right—42% Too long—0%	
14. What PEEC activity do you feel you learned the most from?	Braille Trail—30% ASE's—15%	
15. What PEEC activity did you enjoy the most?	Tumbling water—35%	
16. What activity do you think should have been omitted?	No consistent answer	
17. What impressed you most about the PEEC area?	Scenery	

SUMMARY

Nine questionnaires were developed and used to measure the attitudes and awareness of environmental camp users. People at PEEC have already made good use of the techniques and data to improve their program of environmental education.

Most of the study results are so obvious as to speak for themselves. But one particular issue that surfaced continually during the course of the study deserves mention. It concerns the role that environmental camps can play in the development of interpersonal relationships. Most group leaders either openly cited this as a major goal or at least alluded to it as a secondary reason for coming to PEEC. Be it a goal or not, it is a fact that the residential experience, helping each other on hikes and other cooperative group activities did lead to new friendships and understandings. There is clear indication here of an area for fruitful future work. A reasonable working hypothesis would be that people engaged in real tasks that necessitate cooperation, and supplied with some guidance, will form more interpersonal interaction skills and more positive feeling toward others.

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FOREST SERVICE RESEARCH PAPER NE-427
1978
FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
NORTHEASTERN FOREST EXPERIMENT STATION
370 REED ROAD, BROOMALL, PA. 19008

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Abstract

For a more efficient use of the hardwood forest resource, tables were developed for estimating the weight of sawtimber tops, a major portion of logging residue. Regressions were developed for green and dry total treetop weight and treetop weight in material greater than 3 inches dob (diameter outside bark) for each of three species groups: soft hardwoods, hard hardwoods, and mixed hardwoods. Estimates of treetop weights (green) ranged from 763 pounds for an 11-inch dbh (diameter at breast height) tree to 4,165 pounds for a 26-inch dbh tree. Moisture content averaged 62 percent (oven-dry basis), and the average percent bark (green-weight basis) was 23.

THE CONCERN

AN INCREASING DEMAND for wood products from our relatively stable forest resource combined with public pressure to improve our forest land esthetically, has made it necessary for forest managers and wood processors to utilize more of the wood from harvested trees. Logging residues, generally overlooked as potential raw material, comprise a significant part of the unused forest resource. For example, Craft (1976) found that total residue weight was 1.8 times the weight of sawlogs removed. His study also showed the potential usefulness of the residues. These residues yielded 4,700 board feet of sawed products and 52 tons of chips per acre.

The development of strategies for using logging residues requires methods for making low-cost estimates of the amounts available. Since much of the potentially useful residue is in small branches, weight is the most practical measurement. Chips made from this material are sold on a weight basis, too. Published information provides weight estimates for whole trees (less than 10 inches dbh) left in clearcuts or damaged during logging (Phillips 1977, Wartluft 1977, Wiant et al. 1977), and weight estimates of material left at woods landings (Goho 1976). But for sawtimber tops—the other major portion of logging residue—estimates are available for only one species, black oak (King and Schnell 1972). This report provides a practical method for estimating sawtimber top weights for the major Appalachian hardwoods under any harvesting situation.

PROCEDURE

We conducted the field work for this study on three oak-hickory sawtimber logging operations in southern West Virginia and southwestern Virginia. Red oak site indexes for the three stands were 50, 60, and 80.

In each stand, we selected the sawtimber tree closest to each intersection on a two-chain grid. A total of 75 hardwood trees of nine commercially important Appalachian species were included in the sample (Table 4). For each sample tree, we recorded tree number, species, dbh to the nearest 1/10 inch, and total tree height to the nearest foot. The commercial logger felled, bucked, and topped the sample trees before logging.

After the tops (including limbs below the tops) were on the ground, we cut them into manageable pieces and weighed them to the nearest 5 pounds with a 500-pound capacity, straight-spring scale (Fig. 1). Weights were recorded separately for two kinds of material: (1) pieces greater than 3 inches dob, and (2) pieces equal to or less than 3 inches dob.

To determine moisture content and percent bark, we cut a sample disk at random from each size portion of each top (two disks per tree).

Figure 1. Weighing treetop residue in the woods with lightweight portable equipment.

ANALYSIS

To arrive at equations for predicting sawtimber top weights from available tree measurements and characteristics, we had to account for known variations that affect weight: species, tree size (dbh and total tree height), moisture content, tree portion ($\leq$3 inches dob, >3 inches dob, and leaves), site, and operator (logger).

Sample trees came from three different locations, each logged by different commercial loggers. Therefore the site and operator variables were confounded, which made it impossible to isolate the individual effects. Thus the data on these variables were pooled.

Published information on leaf weights is scarce, but indications are that less than 3 percent of treetop weight is in leaves (King and Schnell 1972). To some extent, the effect of leaves was averaged out as we weighed some trees with leaves and some without. However, we did not consider leaf weight in our prediction equations.

Since we chose our trees at random, several species were represented by one or only a few samples. Therefore, we grouped the data in two categories according to the specific gravities of species, which were based on weight when oven dry and volume when green (U. S. Department of Agriculture 1974). Specific gravities for the soft hardwoods (yellow-popular, cucumbertree, and blackgum) ranged from .40 to .46; the hard hardwoods (white ash, hard maple, hickory, and all

oaks) ranged from .55 to .66. We developed separate equations for these two species groups, and one for all hardwoods combined.

We accounted for the effects of moisture content and tree portion by developing separate regressions for green and oven-dry material and for different tree portions.

Results from a series of regression analyses and stepwise regressions indicated that total tree height made no significant contribution to the equations as long as dbh (or a function thereof) was included. Therefore, total tree height was eliminated as a variable.

This left us with dbh as the best predictor for use in the regressions. Dbh is a very practical predictor since it is also used in estimating board-foot volumes in the sawlog portions of the trees.

Plots of treetop weights versus dbh showed that the variance of the weight was not homogeneous. Therefore we tried a number of transformations of the weight to get homogeneous variance. We achieved this with the logarithm of the top weights, and found that a single linear function of dbh gave us the best fit. We developed regressions for green and dry total treetop weight and treetop weight in material greater than 3 inches for each of the three species groups, which made a total of 12 separate regressions (Table 1). From these, we constructed Tables 2 and 3 of treetop weights with corresponding 95 percent confidence intervals for mean estimates for sawtimber with a dbh range of 11 to 26 inches. Table values for the material less than or equal to 3 inches were calculated by subtracting the greater-than-3-inch regression estimates from the total regression estimates. We calculated moisture contents on an oven-dry basis, and bark percentages on a green-weight basis (Table 4).

RESULTS

All regression equations for estimating sawtimber top weights are of the general form: $\ln w = b_0 + b_1 dbh$ (Table 1).

Estimates of sawtimber top green weight ranged from 763 pounds for an 11-inch dbh tree to 4,165 pounds for a 26-inch dbh tree (Table 2); estimates of oven-dry weight ranged from 449 to 2,609 pounds (Table 3). The percent of treetop weight in material greater than 3 inches dob steadily increased from 56 percent to 75 percent as dbh increased from 11 to 26 inches.

Moisture content averaged 62 percent (Table 4). Hard hardwoods had a lower moisture content, 59 percent, than soft hardwoods, 81 percent.

The average percent bark was 23 (Table 4). The 3-inch or smaller material averaged 27 percent, and the material larger than 3 inches averaged 20 percent bark. Soft hardwoods, with an average of

Table 1.—Regression statistics for equations[a] developed in the study (all equations are highly significant)

w (pounds)	b_0	b_1	S.E.	r^2
Soft hardwoods				
Total treetop green weight	5.122	0.1090	0.400	0.51
Total treetop oven-dry weight	4.530	.1092	.379	.53
>3 inch treetop green weight	4.320	.1300	.458	.53
>3 inch treetop oven-dry weight	3.746	.1301	.432	.56
Hard hardwoods				
Total treetop green weight	5.506	.1129	.345	.70
Total treetop oven-dry weight	4.951	.1174	.348	.71
>3 inch treetop green weight	4.700	.1326	.402	.70
>3 inch treetop oven-dry weight	4.166	.1358	.403	.71
Mixed hardwoods				
Total treetop green weight	5.392	.1132	.404	.60
Total treetop oven-dry weight	4.818	.1173	.428	.59
>3 inch treetop green weight	4.590	.1331	.450	.63
>3 inch treetop oven-dry weight	4.038	.1360	.463	.62

[a] All equations are of the form: $\ln w = b_0 + b_1 dbh$, where dbh is diameter at breast height in inches and ln is the natural logarithm function.

Table 2.—Treetop green weights[a] for Appalachian hardwood sawtimber, by dbh class, in pounds[b]

Tree dbh class (inches)[c]	Mixed hardwoods			Hard hardwoods			Soft hardwoods		
	≤3″	>3″	Total	≤3″	>3″	Total	≤3″	>3″	Total
11	337	426 (1.22)	763 (1.19)	379	473 (1.22)	852 (1.18)	241	314 (1.65)	556 (1.54)
12	368	486 (1.19)	854 (1.17)	414	540 (1.19)	954 (1.16)	262	358 (1.55)	620 (1.47)
13	401	555 (1.17)	956 (1.15)	451	617 (1.17)	1068 (1.15)	283	408 (1.47)	691 (1.40)
14	436	634 (1.15)	1071 (1.13)	491	704 (1.15)	1195 (1.13)	306	464 (1.40)	771 (1.34)
15	474	725 (1.13)	1199 (1.12)	534	804 (1.14)	1338 (1.12)	331	529 (1.34)	859 (1.29)
16	515	828 (1.12)	1343 (1.11)	580	918 (1.12)	1498 (1.11)	356	602 (1.29)	958 (1.25)
17	558	946 (1.11)	1504 (1.10)	629	1048 (1.12)	1677 (1.10)	383	686 (1.26)	1069 (1.23)
18	604	1080 (1.11)	1684 (1.10)	681	1197 (1.11)	1878 (1.10)	411	781 (1.26)	1192 (1.22)
19	652	1234 (1.11)	1886 (1.10)	736	1366 (1.12)	2102 (1.10)	439	890 (1.28)	1329 (1.24)
20	702	1410 (1.12)	2112 (1.11)	793	1560 (1.12)	2353 (1.11)	469	1013 (1.31)	1482 (1.27)
21	754	1611 (1.14)	2365 (1.12)	853	1782 (1.14)	2635 (1.12)	499	1154 (1.37)	1653 (1.31)
22	808	1840 (1.15)	2648 (1.14)	915	2034 (1.15)	2949 (1.13)	529	1314 (1.43)	1843 (1.37)
23	864	2102 (1.17)	2966 (1.16)	979	2323 (1.17)	3302 (1.15)	558	1497 (1.51)	2055 (1.43)
24	920	2401 (1.20)	3321 (1.18)	1044	2652 (1.20)	3697 (1.17)	587	1705 (1.60)	2292 (1.51)
25	976	2743 (1.22)	3719 (1.20)	1110	3029 (1.22)	4138 (1.18)	614	1941 (1.69)	2556 (1.58)
26	1032	3133 (1.25)	4165 (1.22)	1175	3458 (1.24)	4633 (1.21)	639	2211 (1.80)	2850 (1.67)

[a] Weights in pounds with 95 percent confidence factors in parentheses for mean estimates. For the upper confidence limit, multiply the mean estimate by the factor. For the lower confidence limit, divide the mean estimate by the factor. Corresponding portions may not add due to rounding.

[b] To convert to kilograms, multiply by 0.454.

[c] To convert to millimeters, multiply by 25.4.

Table 3.—Treetop oven-dry weights[a] for Appalachian hardwood sawtimber, by dbh class, in pounds[b]

Tree dbh class (inches)[c]	Mixed hardwoods			Hard hardwoods			Soft hardwoods		
	≤3″	>3″	Total	≤3″	>3″	Total	≤3″	>3″	Total
11	196	253 (1.22)	449 (1.20)	227	287 (1.22)	514 (1.18)	131	177 (1.60)	308 (1.51)
12	215	290 (1.20)	505 (1.18)	249	329 (1.19)	578 (1.16)	142	202 (1.52)	344 (1.44)
13	236	332 (1.18)	568 (1.16)	273	377 (1.17)	650 (1.15)	154	230 (1.44)	384 (1.38)
14	258	381 (1.16)	639 (1.14)	300	432 (1.15)	731 (1.13)	166	262 (1.37)	428 (1.32)
15	282	436 (1.14)	718 (1.13)	328	494 (1.14)	822 (1.12)	179	298 (1.32)	477 (1.27)
16	308	500 (1.12)	808 (1.11)	359	566 (1.12)	925 (1.11)	193	339 (1.27)	532 (1.24)
17	336	572 (1.12)	908 (1.11)	391	649 (1.12)	1040 (1.10)	207	387 (1.25)	594 (1.21)
18	365	656 (1.11)	1021 (1.10)	427	743 (1.11)	1170 (1.10)	222	440 (1.24)	662 (1.21)
19	397	751 (1.12)	1148 (1.11)	464	851 (1.12)	1316 (1.10)	237	502 (1.26)	739 (1.22)
20	430	861 (1.13)	1291 (1.12)	504	975 (1.13)	1479 (1.11)	253	571 (1.29)	824 (1.25)
21	466	986 (1.14)	1451 (1.13)	547	1117 (1.14)	1664 (1.12)	269	651 (1.34)	919 (1.30)
22	503	1130 (1.16)	1632 (1.15)	592	1280 (1.15)	1871 (1.13)	284	741 (1.40)	1025 (1.35)
23	541	1294 (1.18)	1835 (1.17)	639	1466 (1.17)	2104 (1.15)	300	844 (1.48)	1143 (1.41)
24	581	1483 (1.20)	2064 (1.19)	688	1679 (1.20)	2367 (1.17)	314	961 (1.56)	1275 (1.47)
25	622	1699 (1.23)	2320 (1.21)	738	1923 (1.22)	2661 (1.19)	328	1095 (1.64)	1423 (1.55)
26	663	1946 (1.26)	2609 (1.23)	790	2203 (1.24)	2993 (1.21)	340	1247 (1.74)	1587 (1.63)

[a] Weights in pounds with 95 percent confidence factors in parentheses for mean estimates. For the upper confidence limit, multiply the mean estimate by the factor. For the lower confidence limit, divide the mean estimate by the factor. Corresponding portions may not add due to rounding.

[b] To convert to kilograms, multiply by 0.454.

[c] To convert to millimeters, multiply by 25.4.

Table 4.—Weighted average moisture content and bark percentage, by species, species group, and treetop portion

Item	No. trees	Moisture content[a]	Bark[b]
		- - - Percent - - -	
Mixed (all) hardwoods	75	62	23
Parts greater than 3-inch diameter	75	63	20
Parts 3 inches or less in diameter	75	60	27
Hard hardwoods	57	59	22
Soft hardwoods	18	81	27
Red oak (*Quercus* spp.)	31	67	20
Chestnut oak (*Quercus prinus*)	16	55	25
Yellow-poplar (*Liriodendron tulipifera*)	14	81	28
White oak (*Quercus alba L.*)	6	48	22
Blackgum (*Nyssa sylvatica*)	3	89	24
Hickory (*Carya* spp.)	2	40	26
Cucumbertree (*Magnolia acuminata*)	1	53	26
Ash (*Fraxinus americana*)	1	49	19
Hard maple (*Acer saccharum*)	1	46	28

[a] Oven-dry basis. Weighted according to proportion of treetop weight represented.
[b] Green-weight basis. Weighted according to proportion of treetop weight represented.

27 percent bark, had more than the hard hardwoods at 22 percent.

USE OF RESULTS

A forest manager or logger can make a preharvest prediction or postlogging estimate of the weight left in the tops of hardwood sawtimber once the sawlogs are removed. Knowing the diameter distribution of sawtimber in the sale is all that he needs. The number of trees in each diameter class should be multiplied by the weight per tree shown in Tables 2 or 3. The estimates can be made in either green or oven-dry weights, and can include the entire tops or portions of tops. If the species distribution is also known, separate estimates can be made for hard hardwoods and soft hardwoods.

Suppose a forester wants to predict the total green weight that would be left in treetops after a sawtimber harvest.

The procedure is:

- Identify stand components (e.g., 22-inch dbh hard hardwoods, 18-inch dbh soft hardwoods, etc.)
- Find table value (Table 2) for each stand component (e.g., 22-inch dbh hard hardwoods = 2,949 pounds per top).
- For each stand component, multiply the estimated top weight from the table by the number of trees in that component (e.g., 2,949 pounds per treetop x 3 trees = 8,847 pounds).
- Sum the estimates for each stand component.

If the forester wants an estimate for only the material greater than 3 inches or only the material less than or equal to 3 inches, other columns in Table 2 or 3 are consulted. To determine how much wood fiber can be expected, Table 4 shows the deduction in weight for the percentage of bark. The original moisture contents in Table 4 can be used to estimate weights at any chosen moisture content.

A sensitivity analysis showed that even in the extreme case of a 5 percent error in dbh measurement, the resulting differences in weight estimates in all categories were well within the confidence limits. A more typical error of 3 percent in an 18-inch dbh hard hardwood would result in only a 6.1 percent difference in the total green top weight estimate.

Estimates of whole tree (above ground) weights for hardwood sawtimber can be made by use of these treetop weight estimates in conjunction with sawlog weight estimates presented by Timson (1972). For each tree, the dbh, species, and scaling diameter and length of each sawlog must be known to arrive at a whole tree weight estimate.

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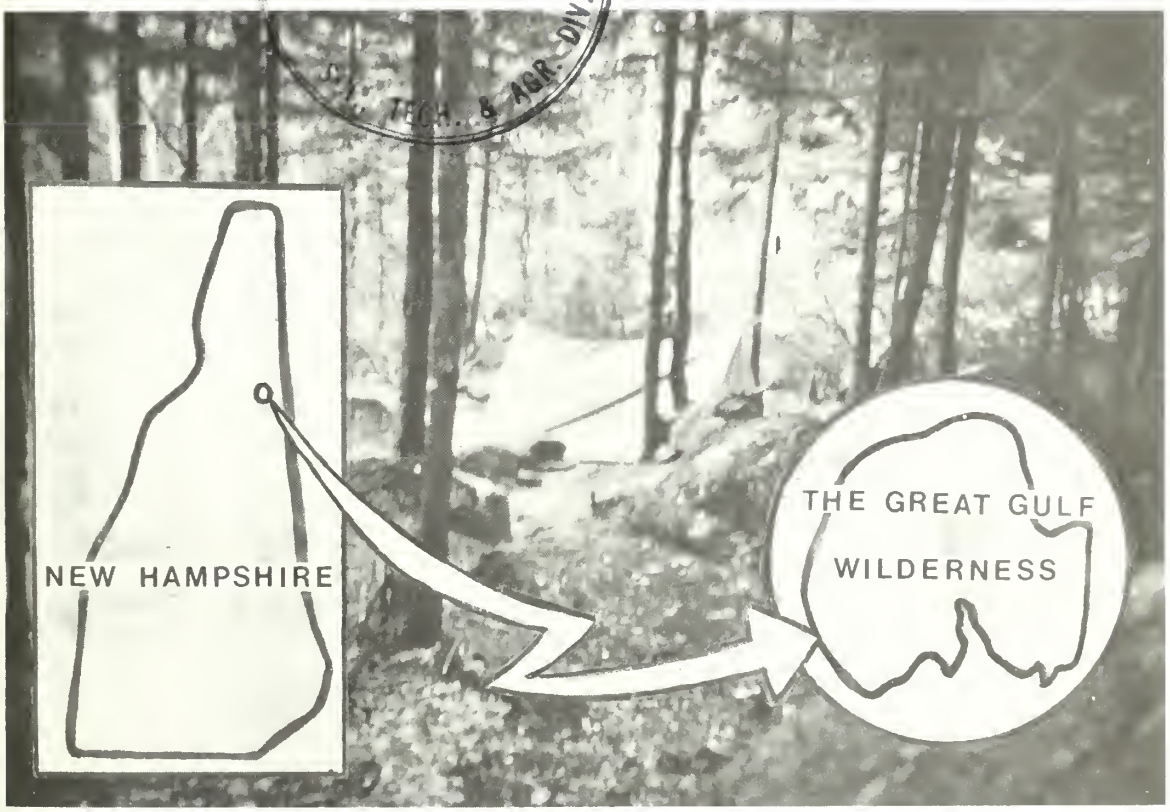

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Abstract

Three use characteristics were studied in the Great Gulf Wilderness of the White Mountain National Forest in 1976: (1) use quantity; (2) use distribution; (3) overnight use patterns. Pressure-plate counters, in conjunction with use permits and site observations, were used to acquire data. Approximately 4,000 people visited this area during the 56-day study period; 75 percent were day users and 25 percent were overnight users. Trail use ranged from 50 hikers per day to negligible use. Overnight users tended to concentrate in the upper portion of the Great Gulf. Actual overnight use was significantly lower than permitted use. On some nights, more than half of the users who obtained overnight permits did not use them.

THE PROBLEM

TWO IMPORTANT FACTORS that affect management of dispersed recreation areas are patterns of current and expected use of an area. This information is especially critical in management planning for wilderness areas in the East where current user densities are high and well-established use patterns are dominant.

In general, use volume alone does not provide sufficient information to develop effective management strategies. A knowledge of use patterns and user behavior is necessary to relate current use to management goals.

For example, Lime and Buchman (1974) described how summaries of use patterns and user behavior can help determine if, where, and when regulation of visitors is needed. The wilderness permit is one tool that they and others (Hendee and Lucas 1973; Lime and Lorence 1974; Fazio and Gilbert 1974) advocated. The information available from permits can be helpful in planning work schedules, selecting locations for public meetings, distributing news releases, and conducting search and rescue operations.

Three major use characteristics needed to develop management strategies are: (1) use quantity, including the number of day and overnight users; (2) use distribution, including average trail use, use by day of week, and popular hiking routes; and (3) overnight use patterns, including user preferences and frequency of overnight use at specific sites.

Wilderness permits would provide this information if all visitors who enter an area obtained a permit. In most cases, a high proportion of visitors do obtain permits before entering a wilderness area. However, in areas where permits have not previously been required, compliance rates may not be high. Godin and Leonard (1977) reported that the compliance rate for one trail in the Presidential Range-Dry River Wilderness was only 55 percent. Also, the validation of trip itineraries, which are written on wilderness permits, is not well documented in the East.

The purpose of this paper is to describe use characteristics for the Great Gulf Wilderness Area of the White Mountain National Forest of New Hampshire and to discuss methods used in acquiring information. The "visitor-day" nomenclature used in Forest Service Recreation Information Management (RIM) calculations was not used in this study. All data in this paper represent actual visits.

THE STUDY AREA

The Great Gulf Wilderness Area in the White Mountain National Forest is a 5,500-acre tract bounded on the south by the Mt. Washington auto road, on the west and north by the northern Presidential Range (Mts. Washington, Clay, Jefferson, Adams, and Madison), and on the east by the Osgood Ridge (Fig. 1). The area, located on the edge of the popular Presidential Range, is a traditional access point for day hikers visiting the summit of Mt. Washington. It is also often used as a starting point for longer backpack trips.

The Wilderness Area includes 10 access points and a total of 18 miles of trail. One major trail follows the valley bottom of the Great Gulf and seven branch trails ascend steeply to the ridges on either side.

Visitor use permits have been required in the Great Gulf since the summer of 1975. Day use is unlimited and permits are available at many nearby locations. Overnight use is limited to 60 persons per night and permits are issued at only two locations.

Dispersed camping is encouraged in this area to promote a sense of solitude for the camper and to help correct resource damage. Camping is prohibited within 200 feet of trails and streams,except at a few designated sites. Wilderness patrolmen

hike the trails to provide information and assistance to visitors, and to ensure that overnight users are camped legally.

VARIABLES STUDIED

Quantification of use

Three methods were used to estimate the number of day and overnight users in the Great Gulf; pressure-plate trail counters, mandatory use permits, and field observation.

Pressure-plate trail counters were installed at eight trail access points in the Great Gulf; two access points where use was negligible were omitted. Each counter consisted of a pressure switch buried a few inches deep in a narrow section of the trail. The switch was connected to a battery and digital counting mechanism concealed in a waterproof container nearby. Each counter was checked twice a week.

Data from wilderness use permits included group size, date of entrance and exit, and entrance and exit points. Field observations were made periodically by personnel stationed at each trailhead; they recorded the permit numbers and the size and direction of each hiking party. Data from all methods were then compared.

Figure 1.—The Great Gulf Wilderness.

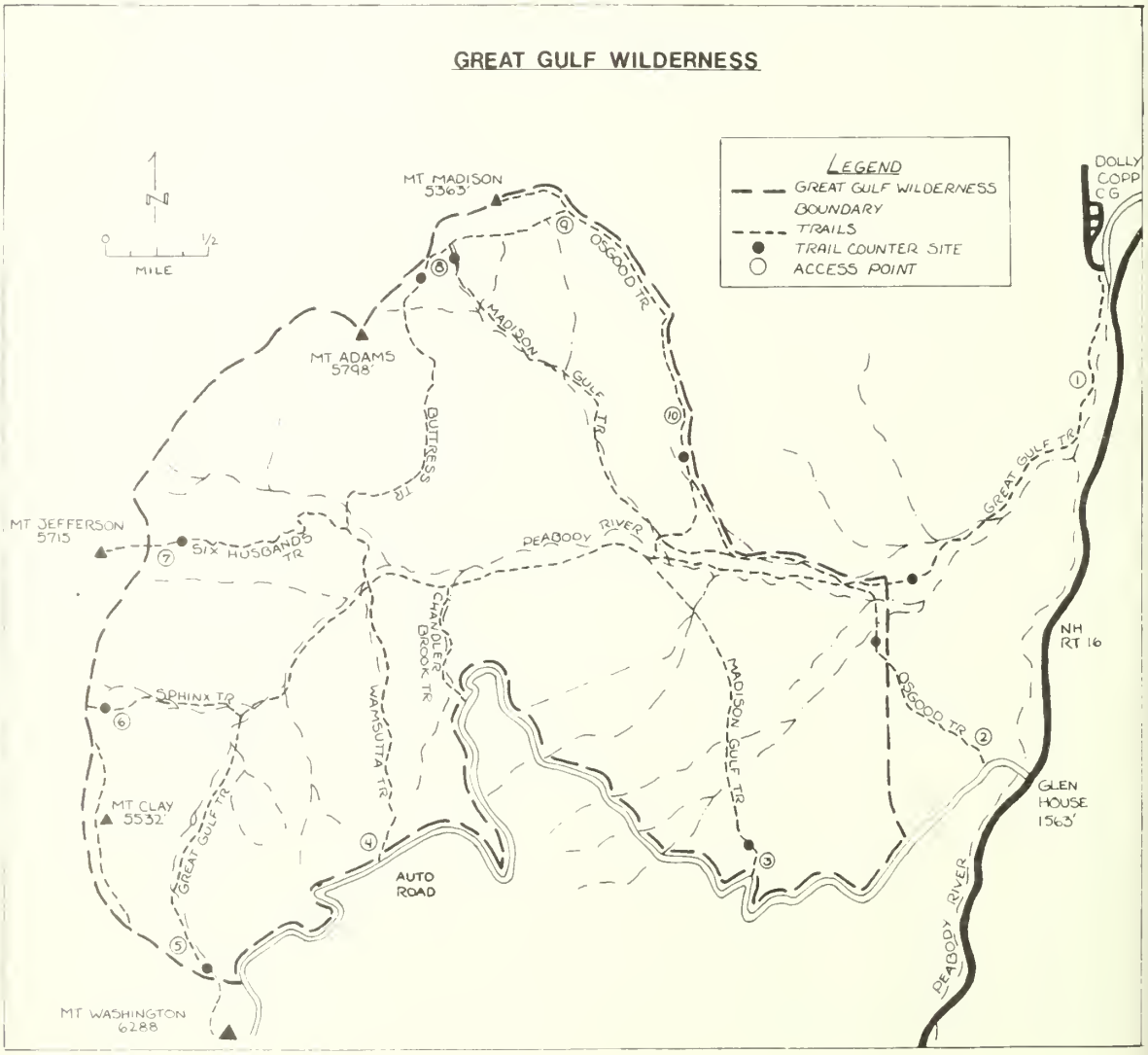
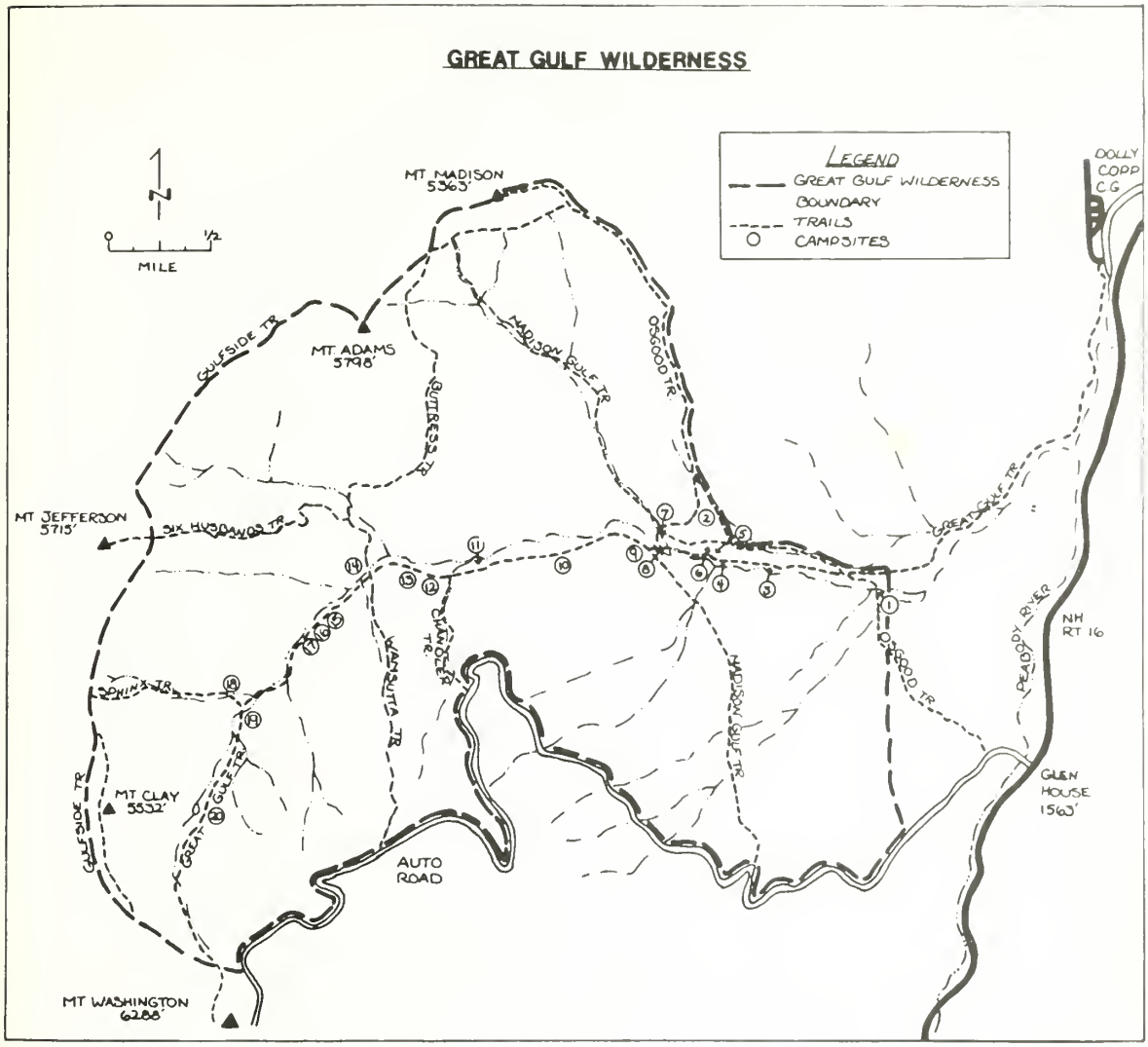


Figure 2.—Established sites along the Great Gulf Trail.



User travel patterns

The primary source of user travel information was the wilderness permit. Use type and entrance and exit data were used to generate frequencies of day and overnight trail use. Popular itineraries were identified by origin and destination.

Overnight use characterization

The objective of this portion of the study was to determine the extent and nature of overnight use. On 15 selected nights, patrolmen recorded permit number, site location, type of use, and group size of campers at 20 sites along the Great Gulf Trail (Fig.2). Although truly dispersed use could not be measured directly, estimates were derived from an observational analysis of other use types. Consideration was given for users who might not have been observed, for users who were noncompliers (did not have permits), and for users who might not have used their overnight permits. Dispersed use was then estimated by subtraction.

Site use frequencies

Schematic maps showing the location of the 20 established sites were prepared for field use by researchers and backcountry patrolmen. Schedules were arranged to facilitate data collection on two to three evenings a week. Permit number, group size, and use types were used to generate average

use frequencies, average group size, compliance rates, and number of groups camped at specific sites. Data on average length of stay, and zip code information were obtained from use permits. Computer analysis yielded aggregate statistics, as well as the relation of group size and zip code origin to use type.

RESULTS

Area use

Total use was determined for the period July 3 through August 27, 1976 (Table 1). The trail counters recorded 7,677 entrances and exits, or 3,838 visitors; the permits show 5,956 entrances and exits, or 2,978 visitors. This difference of 1,721 entrances and exits, 22 percent of the counter total, can be attributed to counter inaccuracy, permit inaccuracy (noncompliance), or both.

The accuracy of individual counters was monitored frequently by observers throughout the summer. In every case, the counter use figure was within 10 percent of the observed value, and frequently within 5 percent. These figures are substantially lower than the 22 percent difference between counter and permit use estimates

Permit error, or noncompliance, is more difficult to measure (Godin and Leonard 1977). However, using the counter figures as a standard, the average permit compliance was 78 percent. This average varied considerably for the 12 intervals observed (Table 1), suggesting that permit data may not accurately reflect actual fluctuations in use. Thus, the permit data may be more useful in providing other kinds of information.

Field observations show the compliance rate for use permits is "apparent" rather than "actual." In the Great Gulf, observers found that many hikers who obtained permits never used them. Most of these users seemed to be overnight visitors who camped outside the wilderness, or who cancelled their trips. Thus, "actual" compliance, those who did use the wilderness and who did have permits, was approximately 65 percent of the total use, substantially lower than the "apparent" value.

Also, the use of adjustment multipliers to compensate for noncompliance can result in inflated figures because these multipliers are predicated on the assumption of 100 percent permit use, an assumption which appears questionable in view of this research.

In summary, there were about 4,000 visitors to the Great Gulf Wilderness Area from July 3 through August 27. Day users accounted for 70 percent to 75 percent of this total; the day users' compliance rate was about 60 percent and overnight compliance was 80 to 90 percent. Trail counters coupled with observational validation provided the best use estimates.

Table 1.—Visitor use and permit compliance in the Great Gulf Wilderness during the summer of 1976, by time interval

Time interval	Entrances and exits		Permit compliance
	Counter recorded	Permit recorded	
	Number		*Percent*
7/3-7/6	700	500	71
7/7-7/9	420	228	54
7/10-7/13	582	345	59
7/14-7/16	464	485	104[a]
7/17-7/21	672	521	77
7/22-7/23	220	174	79
7/24-7/27	497	317	64
7/28-7/30	475	311	65
7/31-8/6	548	447	81
8/7-8/13	548	454	83
8/14-8/20	957	1,027	107[a]
8/21-8/27	1,594	1,147	72
Total	7,677	5,956	78

[a] Compliance rates exceeding 100 percent result from issued permits that were not used, conter error, and permits issued with the wrong date.

Travel patterns

Travel statistics useful to managers include: average trail use, area use by day of the week, and popular hiking routes. Counter data and permit data were useful in assessing average trail use; permit data was the only source of information for assessing the other travel statistics.

Trail use. Counter and permit figures for average trail use differ considerably (Table 2). For example, access point 8 has an average daily use of 23 and ranks third according to counter data; however, access point 8 has an average daily use of 14 and ranks sixth according to permit data. We

Table 2.—Comparison of trail counter and permit data, Great Gulf Wilderness, summer 1976.

Trail	Access No.	Counter data		Permit data	
		Hikers/day	Rank	Hikers/day	Rank
Great Gulf	1	17.2	5	20.5	2
Osgood	2	48.8	1	27.7	1
Madison Gulf	3	22.6	4	16.9	5
Great Gulf	5	7.2	8	19.0	3
Sphinx	6	10.2	6	3.4	8
Six Husbands	7	8.0	7	6.5	7
Buttress	8	22.9	3	13.8	6
Osgood	10	29.1	2	17.2	4

feel that the figures derived from permit data are less reliable than those from counter data because noncompliers are not reflected in permit data, and information from patrolmen indicated that approximately one-third of the groups in the Gulf did not enter or exit at the point indicated on their permit.

From the counter use data, four levels of trail use can be identified. Access point 2, the lower end of the Osgood Trail, had very high use—approximately 50 hikers per day. Access point 10, the upper end of the Osgood Trail, had the next highest use, about 30 hikers per day. Access points 1, 3 and 8, the lower end of the Great Gulf Trail, and the lower and upper ends of the Madison Gulf Trail, respectively, each had about 20 hikers per day. The remaining access points averaged 10 or less hikers per day.

Figure 1 shows that access points 1, 2, and 3 are in the valley while points 8 and 10 are in the Northern Presidentials. This information suggests substantial day traffic along the floor of the Gulf, but that traffic to the ridge along the Wamsutta, Great Gulf Headwall, Sphinx, and Six Husbands Trails is minimal.

Use by day of the week. Permit data can be used to assess daily travel frequencies. Although actual use figures are inaccurate, these data are probably a reasonable estimate. Table 3 shows the proportion of day, overnight, and total use for entrances and exits, respectively, based on permit data. Entrances and exits for day and overnight use were fairly evenly distributed through the week. Overnight use showed small weekend peaks, Saturday for entrance and Sunday for exit. Daily entrances and exits ranged from 11.6 percent to 18.4 percent of the weekly total, a net range of 6.8. Thus, while small weekend peaks can be identified, entrances and exits during the peak season were quite uniform from day to day.

Table 3.—Proportion of trip beginnings and endings for day and overnight visitors, by day of the week[a]

Day	Visitor use		Total
	Day	Overnight	
	- - - - -Percent- - - - -		
Sunday			
Entrances	16.5	12.1	14.6
Exits	16.3	19.9	17.9
Monday			
Entrances	11.4	11.9	11.6
Exits	11.2	13.5	12.2
Tuesday			
Entrances	14.3	14.6	14.4
Exits	14.4	10.9	12.9
Wednesday			
Entrances	11.7	15.2	13.2
Exits	11.6	11.5	11.7
Thursday			
Entrances	13.2	12.9	13.1
Exits	13.3	16.6	14.6
Friday			
Entrances	15.4	13.8	14.7
Exits	15.5	14.0	14.8
Saturday			
Entrances	17.5	19.6	18.4
Exits	17.7	13.7	15.9

[a] Based on permit data.

Popular hiking routes. Although noncompliance and changes in visitor itineraries affect the reliability of route frequency data, this information still may be valuable as a rough indication of day and overnight hiking patterns. On the basis of

Table 4.—Popular hiking routes of day and overnight campers in the Great Gulf Wilderness Area, by entrance and exit and percent of total use[a]

Day users			Overnight users		
Travel route		Percent of total day use	Travel route		Percent of total overnight use
Entrance	Exit		Entrance	Exit	
10	3	12.6	2	2	14.7
8	3	7.1	1	1	11.6
3	8	6.7	1	5	6.3
3	3	6.6	5	3	6.2
1	1	5.5	3	5	5.0
10	2	4.7	5	5	4.9
3	10	4.6	2	5	4.9
2	2	3.9	5	1	3.5
8	2	3.3	5	2	3.0
2	5	2.3	10	5	2.8
2	10	2.3	10	1	2.7
5	1	2.3	3	3	2.6
5	2	2.3			

[a] Based on permit data.

use permits, Table 4 shows the popular itineraries planned for day and overnight users. Of the most popular day routes, eight were "through trips" from valley to ridge or vice versa, and five were "loop" trips. Most of this information is consistent with counter data; however three of these top routes included access point 5, the top of the Great Gulf Headwall on Mt. Washington. Counter data in Table 2 suggest that while people may originally have intended to follow that route, their plans somehow changed.

Of the top overnight routes, eight routes either began or ended at point 5. This figure also seems unreasonable in view of counter data and may have resulted either from changed itineraries or from the observed high percentage of overnight no-shows.

At first glance it seems that the Great Gulf may be a conduit to the Presidential Range; however, this is not the case. Only 42 percent of the day users and less than 10 percent of the overnight users planned to travel routes that provided quick access to or from the Presidential Range:

The remaining routes were loops beginning and ending at the same point or on the same side of the Wilderness Area. For most visitors, the Great Gulf is probably more often considered a destination in itself.

Overnight use characterization

A total of 45 percent of the permitted overnight use was observed at the 20 known trailside sites along the Great Gulf Trail. The standard deviation was 15 percent.

A number of factors must be evaluated before this figure can be used. First, the effect of noncompliers on the observed population must be assessed. For the 15 nights surveyed, compliance was 96 percent, so noncompliance had a very small effect. If the data are adjusted to reflect only overnight compliers, 43 percent of the permitted use was observed.

Second, it was not possible to monitor all 20 trailside sites on a given night.

Third, observational data suggest that many overnight use permits were never used; actual

Use Permit	Route (Entrance-exit)								
	2-8	2-10	3-8	3-10	8-2	8-3	10-2	10-3	Total
	Percent								
Day	1.2	2.3	6.7	4.6	3.3	7.1	4.7	12.6	42.5
Overnight	1.2	0.6	0.8	1.3	0.5	0.8	0.4	0.6	6.2

overnight use was as low as 50 percent of the permitted overnight use for some nights. That actual overnight use is lower than permitted overnight use means that the trailside component of this reduced use figure is greater than 45 percent.

From the theoretical perspective, then, up to 55 percent of the overnight use in the Great Gulf may be truly dispersed. Practically, however, given that actual overnight use is less than permitted overnight use, the truly dispersed component of the actual use is probably much lower, perhaps as low as 30 percent.

Overnight use dispersal in the Great Gulf was a new management policy in 1976; hence, this large trailside component is not surprising. It is reasonable to expect that a transition to dispersed use will take some time to achieve. As users become more familiar with the new management scheme, and user education efforts intensify, the dispersed component of overnight use in the Great Gulf will probably increase.

Site use frequencies

The 20 sites were split into two groups (Fig. 2). Sites 1 through 11, which comprised Group A, are the most easily reached from the road. Sites 12 through 20 (Group B) are more remote. Within each group, several sites accounted for most of the use:

Site	*Occupancy rate*	*Groups per occupied night*	*Group Size*	*People per night*
	Percent		*Number*	
Group A				
1, 3, 4, 5	28	4.8	3.1	4.2
Group B				
14, 17, 19, 20	53	6.1	3.0	9.7

Overnight use in the upper Gulf (Group B) was significantly greater than use in the lower Gulf (Group A). The four sites in the upper Gulf averaged about 10 people per night, while those in the lower Gulf averaged only four people each night.

In the upper Gulf, Site 14, at the junction of the Great Gulf and Six Husbands Trails, was occupied on 92 percent of the surveyed nights, and averaged more than two groups each night. Site 19, at the junction of the Great Gulf and Sphinx Trails, was also heavily used. Only one site in the lower Gulf approached the use levels of sites in the upper Gulf—Site 4, near the Old Bluff Shelter Site. When the Gulf is viewed as a whole, though, it appears that overnight use concentrates principally in eight specific sites.

Overnight permit compliance was higher in the upper Gulf than in the lower Gulf. Compliance averaged 95 percent at Group B sites, 77 percent at Group A sites, and 84 percent throughout the Gulf.

Descriptive factors

The average group size was 3.03 for day use and 2.96 for overnight use. Over half the visitors traveled in groups of two or less. Beyond this equivalence in group size, the shapes of the respective group size distribution curves are also similar. For day and overnight use alike, 70 percent of the groups had six members or less, and 95 percent of the groups had eight members or less.

The average length of stay for overnight users was approximately two (1.99) nights per group. Overnight use in the Great Gulf is limited to a maximum of four nights, but the preponderance of one-, two- and three-night visits indicates that this regulation is not overly restrictive.

Finally, zip codes on permits indicated that Eastern Massachusetts accounted for 24.9 percent of the day use and 21 percent of the overnight use (Table 5). New Hampshire, Connecticut, and New York each accounted for approximately 10 percent of both day and overnight use.

Table 5.—Origins of Great Gulf Wilderness users.

Region	Percent of day use	Percent of overnight use
Eastern Massachusetts	24.9	21.0
New Hampshire	14.9	11.9
Connecticut	10.7	11.1
New York	8.5	11.0
New Jersey	6.3	5.9
Canada	5.6	5.9
Western Massachusetts	4.6	5.0
Pennsylvania	4.1	5.9
Maine	3.6	3.7
Rhode Island	2.6	1.5
Vermont	1.6	2.7
Other	12.7	14.3

There is additional evidence that most people who seek a wilderness experience in the East do so in small groups (two to three people), that their trips are of short duration (over half are day users and most overnight users spend only one to three nights), and that travel from residence to destination is not lengthy—usually about a half day or less (Echelberger and Moeller 1977).

Furthermore, these characteristics are similar to those for people who seek a wilderness experience in the West. Hendee et al. (1968) found that wilderness trips in the Pacific Northwest lasted for about 2.3 days, though length of stay probably varied by size and accessibility of areas. While sampling users of randomly selected wilderness areas in California, Vaux (1975) found that 96 percent lived less than a day's drive from where they were interviewed.

SUMMARY

A comprehensive use inventory to monitor key facets of backcountry use can be generated using existing or easily developed techniques. Trail counter data coupled with those from observations provided good use estimates. Permit estimates suffer from the effects of noncompliance and trip cancellations (predominantly overnight), but provide other information not available from counter and observations.

Although use permits were used extensively in this analysis, use can be characterized by other techniques. In fact, this study demonstrates that trail counters can provide better use estimates than wilderness permits. In either case, observations are necessary to verify the accuracy of the data.

Area use

- There were approximately 4,000 visitors to the Great Gulf during the study period. About one-quarter were overnight visitors.
- Actual permit compliance was 60 percent for day use, 85 percent for overnight use, and 65 percent overall.

Travel patterns

- Trail use ranged from 50 hikers per day to negligible daily use.
- Hiker travel was fairly evenly distributed throughout the week.
- The most popular hiking itineraries involved "loop" trips along the Gulf floor or "through" trips to the northern peaks. Comparison of permit and counter data indicated that actual hiking patterns differed significantly from planned itineraries.

Overnight use patterns

- An average of 45 percent of the permitted overnight use was observed in the trailside sites. Observational data suggest that actual overnight use was substantially lower than permitted use due to a large number of visitors who did not stay in the Great Gulf overnight, that 70 percent to 100 percent of the actual overnight use may have been concentrating along the trails, and that the "dispersed" component of overnight use was relatively small.
- Most of the overnight use was in the upper Gulf, where four sites were popular. Overnight users in general had a high permit compliance rate and tended to camp in 8 to 10 popular sites.

Other factors

- Average group size was approximately three people; 95 percent of all groups had eight members or less.
- About 60 percent of the Great Gulf users live in New England. The largest percentage came from Eastern Massachusetts, followed by New Hampshire, Connecticut, and New York.
- The average length of stay for overnight users was two nights.

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A Comparison of Four Techniques For Producing High-Grade Furniture Core Material From Low-Grade Yellow-Poplar

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Abstract

Four methods of converting low-grade yellow-poplar lumber into high-grade furniture core material (lumber core) were compared. High-grade core material is used in tops, shelves, doors, and drawer fronts and only minor defects are allowed. Three gang-rip first and the conventional crosscut-first manufacturing sequences were evaluated in combination with 1 Common, 2A Common, and 2B Common lumber. Results based on costs and yields indicate that 2A and 2B Common lumber and either of two gang-rip first techniques would be the most effective choices.

INTRODUCTION

IN RECENT YEARS, yellow-poplar lumber has become abundant, especially in the lower grades. Because of this increase in availability and current lumber costs, the continued use of yellow-poplar as furniture core material would be assured if the current cost of lumber core could be maintained or lowered.

Achieving this goal requires the use of low-grade lumber in combination with an efficient low-cost manufacturing technique. Failure to do this would result in the loss of the furniture core market to particleboard, fiberboard, and other substitute materials.

Core panels are used as center fill material for laminated products. High-grade lumber core cuttings—such as those used in tops, shelves, doors, and drawer fronts—can contain only minor defects such as stain, small bird pecks, small burls, pin knots, and pinworm holes.

In this study, I attempted to determine the most efficient techniques for producing furniture core from low grades of yellow-poplar.

In actual cutup tests or through computer simulation, I compared the following manufacturing sequences:

- Crosscut-rip
- Gang-rip crosscut
- Gang-rip longest length
- Gang-rip finger joint.

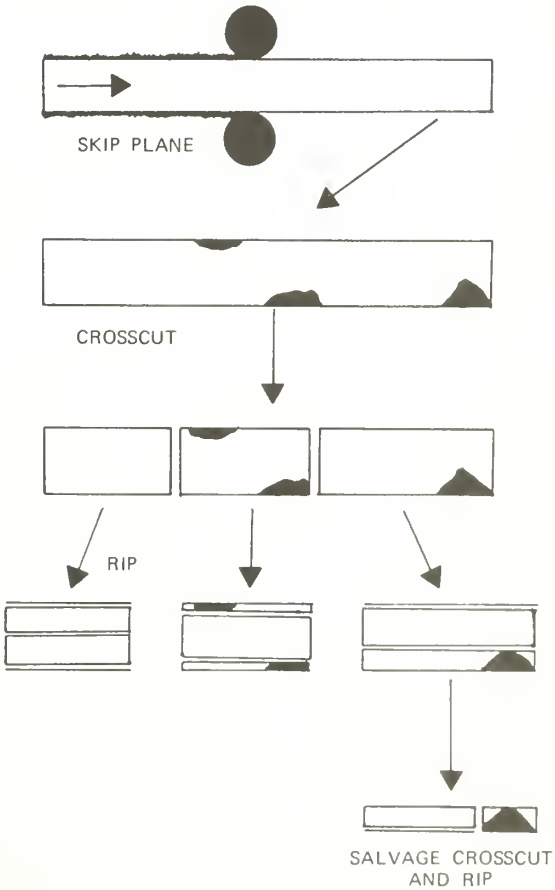
In all tests I used kiln-dried 4/4 yellow-poplar lumber in grades 1 Common (1C), 2A Common (2AC), and 2B Common (2BC). In making the comparisons, I also considered the:

- Optimum ripping width when gang ripping
- Costs for lumber, transportation, drying, handling, rough milling, and overhead
- Ease of manufacture and the frequency of operator error.

Crosscut-rip

In this traditional method, the lumber is skip planed and then crosscut to required lengths (Fig. 1). The crosscut saw operator uses a back-gage in deciding where to cut a board to the required length while maximizing usable material. Random-width cuttings are ripped from the cut-to-length boards. Pieces containing defects are sent

Figure 1.—Crosscut-rip manufacturing sequence.



to a salvage crosscut and rip operation where smaller cuttings are produced.

Each of the following gang-ripping methods included the following steps:

- Crosscut warped lumber to shorter lengths to remove bow or crook (maximum allowable deflection of 5/16 inch)
- Rough plane the lumber
- Gang rip the lumber into strips of equal width (Fig. 2).

Gang-rip crosscut

In this method, strips fron the gang-ripping operation are crosscut to specified lengths. The crosscut saw operator used a back-gage to maximize recovery from the strips. Cutting bills usually include five lengths (one primary and four secondary). The primary length represents the longest length of the five cuttings and is the most difficult to obtain. The secondary cuttings provide a range of cutting lengths.

Gang-rip longest length

In this method, strips from the gang-ripping operation are sent to a defecting station where objectionable defects are removed by crosscutting. Each random-length piece is then crosscut to the longest length needed.

Gang-rip finger joint

As with the longest length method, strips are sent to a defecting station for removal of objectionable defects by crosscutting. The resulting random-length pieces (minimum of 8 inches) are sent to a finger jointing station where the ends are machined and glued together in a continuous strip. This strip is then cut to each of the required lengths. Finger jointing results in a loss in usable length of 7/8 inch per joint (Fig. 3), and in a loss in width of 1/8 inch.

MATERIALS AND METHODS

Ripping width simulation

I used computer simulation to determine the effect of ripping width on the yield in strips and edgings for use in the gang ripping sequences. For samples of 1C, 2AC, and 2BC yellow-poplar lumber, the computer simulation included 9 ripping widths ranging from 1.0 to 3.0 inches (Table 1).

All salvage edgings were evaluated as though they had been processed to random widths (minimum of 1 inch). The yields were added to those from the strips. The simulation also included a 7/16-inch hogging head cut on the leading edge of each board to produce a glueline edge; a 3/16-inch kerf was used for all other saws.

Figure 2.—Gang ripping a board into strips and an edging.

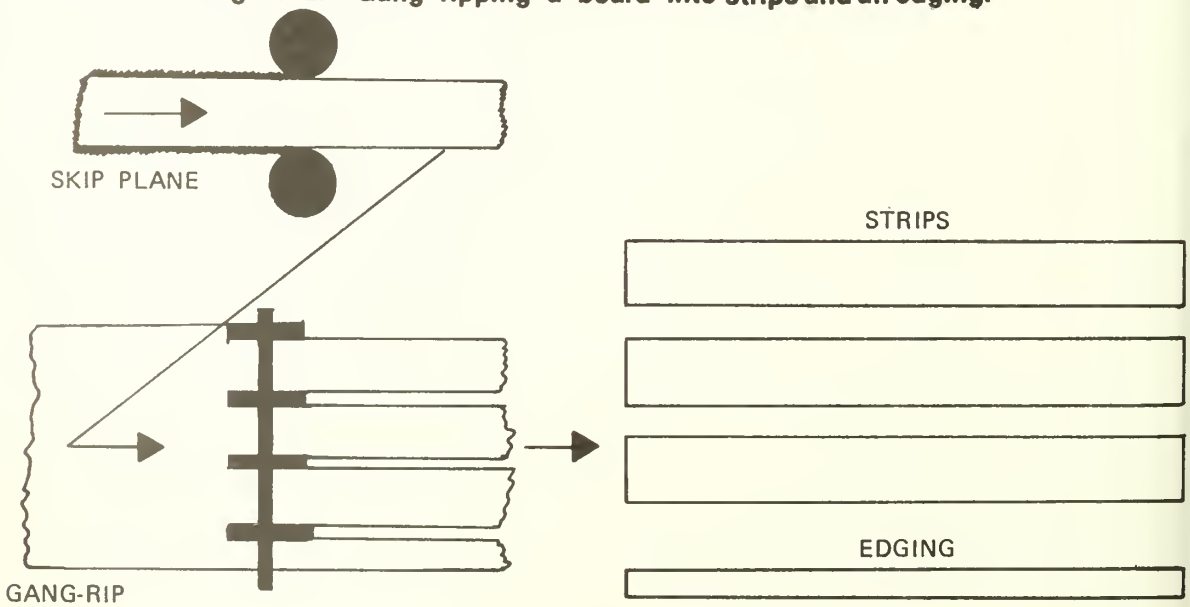
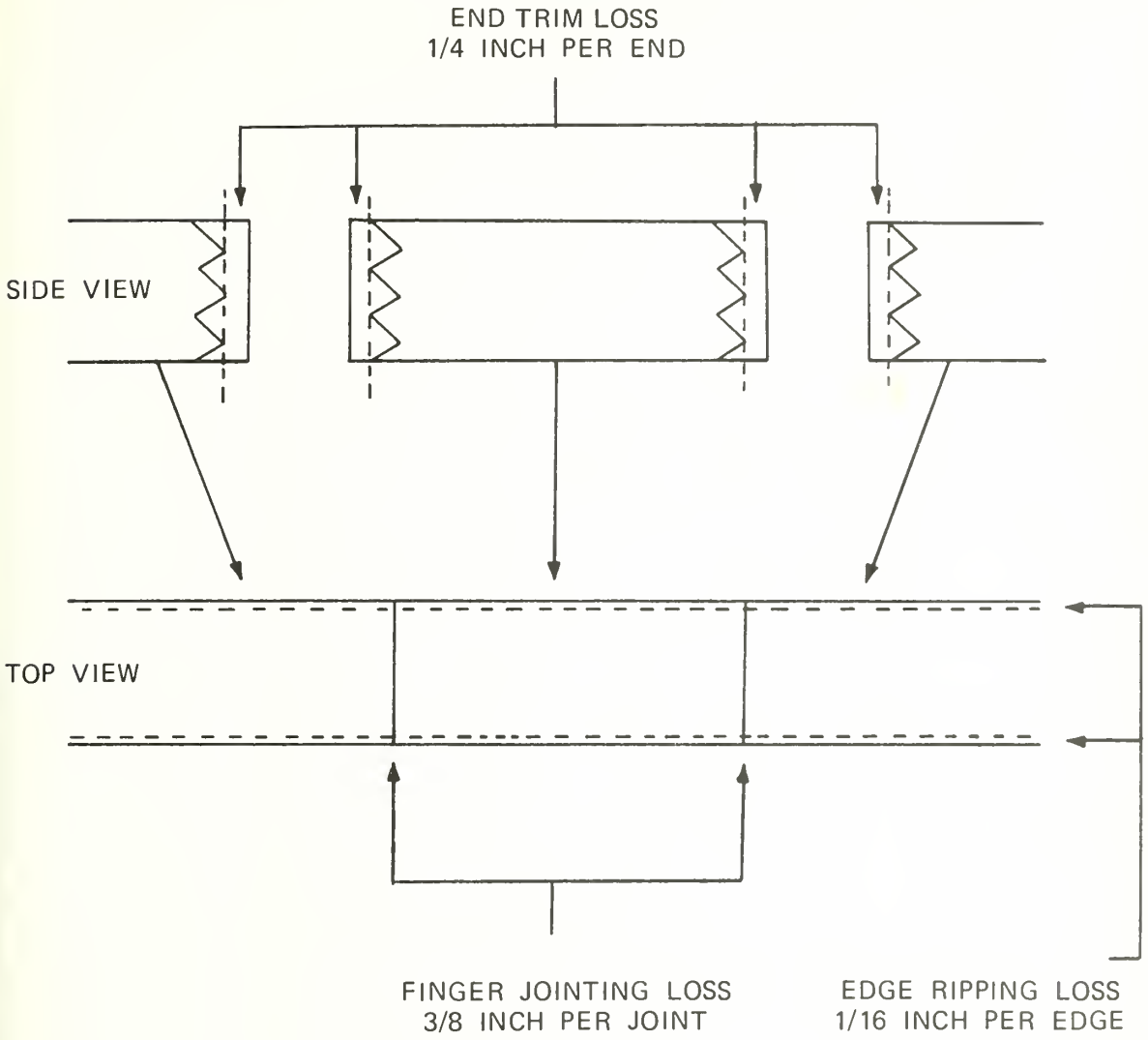


Figure 3.—Losses from finger jointing pieces of wood to be used in core panels.



TOTAL LOSSES IN LENGTH WITH ONE JOINT =

1/4 + 1/4 + 3/8 = 7/8 INCHES

TOTAL LOSSES IN WIDTH = 1/16 + 1/16 = 1/8 INCH

The total yield in undefected strips and undefected edgings (wider than 1 inch) ranged from 75 to 88 percent (Table 1). The yields differed slightly between the lumber grades for a given ripping width. As the strip width increased, the yield in edgings along with the total yield increased. These results are important in considering a gang-ripping operation because edgings are difficult to handle and are costly to process.

I selected two widths for further testing: the 3-inch ripping width because it produced the highest total yield and the 2.25-inch width because the total yield was high and few edgings would require processing.

Table 1. Simulated gang-ripping yields in undefected strips and edgings (wider than 1 inch) by lumber grade and strip width

Strip width (inches)	1C		Total	2AC		Total	2BC		Total
	Strips	Edgings		Strips	Edgings		Strips	Edgings	
	percent								
3.00	68	18	86	71	15	86	72	16	88
2.75	69	18	87	72	13	85	72	15	87
2.50	72	12	84	72	13	85	72	14	86
2.25	75	9	84	75	10	85	77	7	84
2.00	75	7	82	75	8	83	76	7	83
1.75	75	6	81	76	5	81	79	4	83
1.50	76	4	80	76	3	79	77	2	79
1.25	77	0	77	77	0	77	77	0	77
1.00	76	0	76	75	0	75	76	0	76

Table 2. A typical distribution of furniture core requirements in a cutting order

Cutting No.	Length of glued panel (inches)	Percent of total output
1	81	3
2	70	2
3	65	2
4	58	8
5	45¼	10
6	40	22
7	32½	9
8	26	18
9	21	20
10	16¼	6

Rough mill tests

The production of a list of required cuttings was simulated for the gang-ripping tests and physically processed for the crosscut-rip tests. The cutting order approximated that of a typical furniture manufacturer (Table 2). The cutting order required glued panels ranging in length from 16 1/4 to 81 inches. Required quantities were expressed as a percentage of total output.

The computer simulated the gang-rip sequences in the following manner:

Gang-rip crosscut. The initial cutting bill included cuttings 1, 3, 5, 7, and 9 from the list of cuttings (Table 2). The primary length is the longest of the five because it is hardest to obtain. The secondary cuttings are selected to provide a range of cutting lengths. When the requirements for one of the five lengths were satisfied, it was replaced by the next longest cutting. This procedure was repeated until the total required cuttings for the 10 lengths are sawed.

Gang-rip longest length. All 10 lengths in the list of cuttings are initially set up at the crosscut station. As the requirement of any length cutting was satisfied, that length was simply removed from the setup.

Gang-rip finger joint. After finger joining, the continuous usable strips were cut—one at a time—to each of the required lengths. The cuttings were then re-edged for gluing into panels.

For all three gang-ripping methods, edgings were manufactured into random-width cuttings by simulation. The edgings were first cut to required lengths by the longest length method. The pieces were then ripped to random-width cuttings (1 inch minimum) by removing the rough edge. Results were then added to the cutting yields from the strips.

Crosscut-rip. In a physical yield test, the lumber was crosscut to one of five lengths in a cutting bill with one primary and four secondary cuttings (cuttings 1, 3, 5, 7, and 9 from the list of cuttings). As the cutting requirements for a length were satisfied, the requirements for the next longest cutting were added to the cutting bill. This procedure was repeated until the requirements of the 10 lengths were sawed.

RESULTS

In the gang-ripping tests, the average yield in core material for 1C, 2AC, and 2BC lumber was 66 percent for the 2.25-inch strips and 61 percent for the 3-inch strips. Individual yields by lumber grade and manufacturing method ranged from 43 to 73 percent (Table 3). The lower yields for the 3-inch strips probably were caused by the greater loss of wood (volume) when a defect had been removed and by the greater probability that objectionable defects would be found. Because of the higher average yield, the gang-rip methods using the 2.25-inch strip width were used in further comparisons with the crosscut-rip method.

The yield in core material from 1C lumber for the crosscut-rip method was 78 percent (Table 3). Yields from 1C lumber for the 2.25-inch strip width were 72 percent each for the gang-rip crosscut and gang-rip finger joint sequences and 70 percent for the gang-rip longest length method.

Yields in core material for 2AC lumber were similar for all four manufacturing methods (Table 3). For 2BC lumber, the yield for the crosscut-rip method was 53 percent, 1 percent higher than that for the gang-rip crosscut method. Yields from 2BC lumber for the gang-rip longest length and gang-rip finger joint methods were 59 and 63 percent, respectively.

However, the average yield when all lumber grades were combined was similar for all manufacturing methods (Table 3).

Table 3. Yield in core material from the rough mill tests

Manufacturing sequence	Lumber grade			Average
	1C	2AC	2BC	
	- - - percent - - -			
3.0-INCH STRIP WIDTH				
Gang-rip finger joint	72	65	59	65
Gang-rip crosscut	70	60	43	58
Gang-rip longest length	69	61	49	60
Average	70	62	50	61
2.25-INCH STRIP WIDTH				
Gang-rip finger joint	72	73	63	69
Gang-rip crosscut	72	68	52	64
Gang-rip longest length	70	69	59	66
Average	71	70	58	66
Crosscut-rip	78	72	53	68

DETERMINING COSTS

The yield by grade of lumber is only one of several factors that must be considered in determining the most efficient method of converting low-grade yellow-poplar lumber into furniture core material. One also must consider the cost of lumber by grade, transportation from the mill, handling, air drying, kiln drying, rough milling, and overhead expenses. In determining the most economical combinations of lumber grade and manufacturing method, I calculated the total cost per 1,000 board feet (MBF) of core material for each combination by the following equation:

$$TC = \frac{(LC + AOC)}{\%\ \text{yield}}$$

where

TC = total cost/MBF of core material
LC = lumber cost/MBF
AOC = all other costs/MBF
% yield = yield in core material for a given grade of lumber processed by a given manufacturing method.

Lumber costs per MBF for 4/4 Appalachian yellow-poplar lumber were obtained from the Hardwood Market Report of November 1977 (1C: $220; 2AC: $135; 2BC: $110). A fixed charge of $160 was assigned for all other costs (AOC). This figure was obtained from a cooperator with a modern conventional rough mill.

It might seem that lumping all costs other than that for lumber is a gross simplification. But consider the effect of an increase of or decrease of $20 in AOC cost on the total cost per MBF of core material (Table 4). For 1C lumber, an AOC of $160 resulted in a total cost of $521 per MBF of core material when the lumber cost was $220 and the average yield for all four manufacturing methods was 73 percent. An increase or decrease in the AOC of 12.5 percent changed the total cost of the core material by only $28 (plus or minus).

Thus a change in AOC of 12.5 percent resulted in a change in total costs of only 5 percent. For 2BC lumber, a similar change in AOC had a slightly greater effect on the total cost—7 percent (Table 4).

Of greater importance than the effect of changes in AOC is the effect of the combination of lumber cost and yield by grade of lumber. Table 4 shows that compared to 2AC lumber, 1C is high in price and produces only a slightly higher yield, and that 2BC is low in price and produces a

lower yield. Given a choice of only one grade to use, 2AC would be preferred because of its relatively high yield and low price and the corresponding lower total cost per MBF of core material.

When 2AC and 2BC yellow-poplar were considered individually by manufacturing method, the total cost of core material ranged from $404 to $519 per MBF (Table 5). When these grades were combined in a 50-50 mix, the gang-rip finger joint and longest length methods produced lower total costs—$0.42 and $0.44 per square foot, respectively.

DISCUSSION

Gang-rip crosscut

This method was the most expensive, $0.48 per square foot, and yielded less core material than the other gang ripping methods when 2AC and 2BC were combined (Table 5), even though the use of material between defects was maximized with the aid of a back-gage. Also, decisions required by the crosscut saw operator would make it difficult to achieve the yields obtained for this method in the laboratory.

Table 4. Effect of variation of AOC on total costs/MBF of core material by lumber grade (2.25-inch strip width)

Lumber grade	Average yield for all methods	Lumber/ MBF	Total cost when--		
			AOC = $140	AOC = $160	AOC = $180
	percent		*dollars*		
1C	73	220	493	521	548
2AC	71	135	387	415	444
2BC	57	110	439	474	509

Table 5. Total cost/MBF of core material, by manufacturing sequence and lumber grade

Manufacturing sequences	Lumber grade	Percent yield	Total costs/ MBF[a]	Average total costs/MBF[b]	Average total costs/BF[b]
			dollars		
Gang-rip crosscut	2AC	68	434		
				477	0.48
	2BC	52	519		
Gang-rip longest length	2AC	69	428		
				443	.44
	2BC	59	458		
Gang-rip finger joint	2AC	73	404		
				417	.42
	2BC	63	429		
Crosscut-rip	2AC	72	410		
				460	.46
	2BC	53	509		

[a] AOC = $160
[b] 50-50 mix of 2AC and 2BC lumber

Gang-rip longest length

For this method, the cost of core material was $0.44 per square foot when grades 2AC and 2BC were combined. This method is simple and yields are easily obtained. This method also can be highly automated and there is little chance of operator error.

Gang-rip finger joint

This method had the lowest average cost—$0.42 per square foot (Table 5). However, the costs of this method may be greater than estimated because of the additional costs for finger jointing. This method is simple and can use material as small as 8 inches long. There also is little chance of operator error with the finger joint method because decisions are required only when objectionable defects are removed.

Crosscut-rip

The average total cost for this method was $0.46 per square foot (Table 5). This cutup technique is by far the most susceptible to operator error of all methods studied, so it would be difficult to achieve the laboratory yields in actual production. However, a well-run, efficient conventional rough mill using only 2AC lumber would be an acceptable but not the best choice for producing high-grade core material.

Using only 2BC lumber would cause serious problems because decisions required of a crosscut saw operator are overwhelming when attempting to find long cuttings in 2BC lumber. Also, the back-gage was not helpful in tests with 2BC lumber. The number and location of objectionable defects in 2BC boards would make crosscutting difficult. By contrast, defects are easier to locate and remove in gang-ripping operations.

CONCLUSION

The results of this study indicate that 2AC is the most economical grade in converting low-grade yellow-poplar lumber into furniture core material. Ideally, a combination of 2AC and 2BC lumber should be used. The more highly automated and error free gang-rip finger joint and gang-rip longest length manufacturing methods were the most efficient in processing these grades.

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A COST ANALYSIS: PROCESSING MAPLE SYRUP PRODUCTS

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Abstract

A cost analysis of processing maple sap to syrup for three fuel types, oil-, wood-, and LP gas-fired evaporators, indicates that: (1) fuel, capital, and labor are the major cost components of processing sap to syrup; (2) wood-fired evaporators show a slight cost advantage over oil- and LP gas-fired evaporators; however, as the cost of wood approaches $50 per cord, wood as a fuel would no longer have this cost advantage; (3) economies of scale exist in processing maple sap to syrup; (4) in 1977 the total cost of production, including both sap production costs and processing costs, for a medium-size (750) gallons of syrup) operation was $8.36 per gallon of syrup for oil-fired evaporators, $7.97 per gallon of syrup for wood-fired evaporators, and $8.37 per gallon for LP gas-fired evaporators.

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INTRODUCTION

THE ECONOMICS of processing maple sap to syrup is important to the producer of maple syrup products. Equipment, labor, and energy costs are rising sharply, reducing profits with every incremental increase, and placing many producers in a cost-price squeeze.

Early settlers produced maple syrup primarily as a sweetner for household use rather than as a product for trade, so production costs were not a major consideration. Today, however, maple syrup products are produced as a cash crop to provide supplemental income to the farm. There also is a trend toward large-scale operations that are the sole or primary source of income.

Today's commercial maple processing plants require a substantial investment, and rising costs make it necessary for the industry to fully understand production costs and their efffect on the future supply of maple syrup products. Costs of syrup production can be divided into two components, the extraction and collection of maple sap and the processing of sap to syrup. Although the processing component is evaluated in this paper, a brief summary of sap collection costs is appropriate.

In evaluating costs associated with the production of maple sap, Huyler (1975) and Gunter and Koelling (1975) concluded that the initial investment cost per tap is lower when plastic tubing rather than the traditional metal bucket is used to collect sap. Although the cost varied with the size of an operation (usually lower for larger operations), the average investment cost per tap was $1.74 for the tubing system compared to $2.07 per tap for the bucket system.

The results also showed that the tubing system required less labor time than the bucket system—9.6 minutes per tap for tubing versus 12.3 minutes per tap for buckets. In addition, the preparation and installation of a tubing system requires the greatest concentration of labor before the sap-flow period. The labor is therefore, available for sugarhouse activities as soon as the sap begins to flow. Conversely, a bucket system requires the greatest concentration of labor during sap flow.

A critical finding of the sap production studies was that total annual costs were an average of 8 percent less for a tubing system than for the bucket system. In 1974, an operator using plastic tubing incurred a total annual cost of approximately $0.86 per tap compared to about $0.93 per tap for a similar operation in which buckets were used. Because of lower annual costs, the tubing operator could break even at approximately 900 taps compared to 2,200 taps for a bucket operator. If one assumes an average of four taps to produce a gallon of syrup, the total annual cost of sufficient sap to produce a gallon of syrup in 1974 was $3.44 (4 x $0.86) for tubing systems and $3.72 (4 x $0.93) for bucket systems.

The cost of tubing systems has not increase significantly since 1974. An analysis of these operations in 1977 revealed that the total annual cost of sufficient sap to produce a gallon of syrup was $3.65, an average increase of only $0.21 per gallon syrup equivalent since 1974.

Costs associated with producing sap are nearly one-half of those requried to produce a gallon of syrup. The remaining total costs in producing a gallon of syrup are incurred in the processing plant or the sugarhouse.

It should be understood that the cost of processing sap to syrup is not and should not necessarily be separated from the cost of sap porduction as was done in this study. We took this approach so that producers who are presently producing only sap or who are purchasing sap and processing it to final syrup products can estimate the cost of sap or syrup production or both. this method also is appropriate for potential entrepreneurs who plan to enter either production phase, but not both.

METHODS

Time and motion studies were conducted at nine maple syrup processing plant during the 1974 and 1975 maple seasons. All costs associated with syrup production for each operation were tabulated, including those for land, building, plant equipment, labor, fuel, electricity, and miscellaneous cost items.

Nine "conventional" or stadard sample evaporators as designed by commercial manufacturers were evaluated. These evaporators were separated into three groups by fuel type. Group 1 was No. 2 oil fired, Group 2 was wood fired, and Group 3 was LP gas fired. Within each group were three levels of syrup production, approximately 500, 750, and 1,000 gallons.

Capital, labor, fuels costs, taxes

Capital costs, which include land, building, and plant equipment, were amortized over a 20-year useful life for plant equipment and a 25-year useful life for building and land at 10 percent interest on investment. The cost associated with building construction was based on farm-type structures at a cost of $3.50 per square foot. All equipment costs are based on 1977 prices.

Labor for the production process was charged at a rate of $4.00 per hour. This figure includes the owner-operator and any hired or family labor used in the operation.

Fuel costs were based on average current market prices. The average cost of No. 2 fuel oil was $0.495 per gallon, the average cost of wood was $40.00 per cord, and the average cost of LP gas was $0.505 per gallon. The cost of electricity used was $0.045/kwh. All other miscellaneous costs represent an average of existing market prices for products or services used by the processing plant.

Taxes were estimated at $8.00 per $100.00 and based on 50 percent of the fair market value of land and building. Insurance was estimated at $0.75 per $100.00 of original investment.

Real costs

Since maple syrup production is primarily a farm-oriented business, no two operations have identical production costs. Many have older plants and equipment which are fully depreciated and, therefore, do not carry equipment costs. Further, many operations do not charge the labor rates which we have charged to our labor, and some do not attach a charge for family labor.

To fully evaluate the total annual cost of production, both noncash items, such as interest or borrowed capital, depreciation expense on building and equipment, and cash items, such as labor, fuel, electricity, taxes, insurance, and any miscellaneous expense, should be combined to determine the total annul cost of production.

RESULTS AND DISCUSSION

Essential to any new business are two forms of capital, investment capital which makes it possible to assemble the physical resource required for production, and operating capital, which is used after the physical resource has been assembled. When the production process begins, other costs—such as labor, energy, and a multitude of miscellaneous costs—are incurred.

Capital investment

An operating maple producer or an entrepreneur planning to invest in maple syrup processing plant must allocate monies for items such as land, processing equipment, building, and storage facilities. For the operators studied we found that total capital investment increases as plant size increases; however, land and building costs do not increase in direct proportion to the volume of syrup produced because 1 acre of land is sufficent for both small and large operations, and building size does not double as volume doubles.

A breakdown of total capital investment for small, medium, and large maple syrup operations by fuel type is shown in Table 1. Small, medium, and large maple operations using oil, wood-, or gas-fired evaporators differed little in total capital requirements. Small plants required an outlay of approximately $8,500, whereas medium- and large-size plants required approximately $9,500 and $11,500, respectively.

Processing equipment represents the largest single component of the total investment cost for processing maple sap to syrup—aproximately 70 percent. Larger operations may also require specialized equipment for syrup draw-off, syrup finishing, and standardizing packaging. However, mechanical filtering, standardizing, and packaging equipment is excluded from the capital investment.

Table 1.—Investment cost for small, medium, and large maple syrup operations

Item	5' x 12' Small 1500-2000 taps 375-500 gal syrup	Investment Cost 5' x 16' Medium 2100-3000 taps 525-750 gal syrup	6' x 16' Large 3100-4000 taps 775-1000 gal syrup
		Dollars	
Land (1 acre)	1,000	1,000	1,000
Building @ $3.50 ft.^{2}	2,058	2,279	2,387
Wood shed @ $2.00 ft.^{2}	480	672	912
Processing Equipment[a]			
Oil rig	5,481	6,577	8,278
Wood rig	4,591	5,665	6,882
Gas rig	5,501	6,660	7,885
Total oil	8,539	9,856	11,665
Total wood	8,129	9,616	11,181
Total gas	8,559	9,939	11,272

[a]Does not include filter and packaging equipment.

Processing equipment for oil-fired systems require the highest investment and wood-fired systems the least. However, there is an additional cost of a storage shed for the wood-fired system, so the total investment for each system in nearly equal.

Annual production cost

Depreciation and interest. Of the several "noncash" elements in any business, depreciation is usually the least understood and the one that many maple producers disregard in their cost analysis. The primary importance of depreciation is its effect on income taxes; therefore, it will be reflected in the business cash flow and/or net profit.

Although depreciation has many meanings and can be computed in several ways, its use in the context of this analysis is usually termed amortization. The objective is to recover completely the original investment cost by charging an annual amount over the useful life of the the investment. In this case, syrup processing equipment has an estimated useful life of 20 years and the building a useful life of 25 years with no salvage value.

Interest on borrowed capital is also an important cost item in estimating the annual production cost. Interest is simply the rental price of money that has been borrowed to be placed into operation. For this analysis an annual interest rate of 10 percent was charged to the capital investment.

One method of relating both depreciation and interest cost in determining the annual cost of capital is to use a capital recovery factor.[1] This is simply multiplying the original investment by a factor to determine the annual payment needed to recover the original investment plus interest over a specified period. This method was used to estimate the annual equipment cost (interest and depreciation) for each size and type of operation (Table 2).

Capital cost accounts for approximately one-third of the total annual cost for processing sap to syrup (Fig. 1). The annual cost of capital decreases as size increases for each fuel type, indicating that economics of scale exist for larger plants (Table 2). Wood-fired evaporators had a slight cost of capital advantage over the No. 2 oil-fired and gas-fired evaporators, but the difference was marginal.

Labor costs. Labor accounted for 15 to 17.5 percent of the total annual cost of processing sap to syrup. All fuel types and size classes studied required approximately 130 to 140 hours per season for processing. The wood-fired evaporators re-

[1]Capital recovery factor $a = Vo \dfrac{i(1+i)^n}{(1+i)^n - 1}$

where a = the annual payment; Vo = original investment;
i = the rate of interest; n = number of years depreciated.

Table 2.—Annual production costs for small, medium, and large maple processing plants, by fuel type

Item	No. 2 fuel oil			Wood			LP gas		
	Small	Medium	Large[a]	Small	Medium	Large	Small	Medium	Large
	Dollars per gallon of syrup								
Depreciation & Interest									
Land & Building	0.67	0.48	0.37	0.78	0.58	0.47	0.67	0.48	0.37
Processing equipment	1.28	1.03	.97	1.08	.89	.80	1.29	1.04	.93
Taxes & Insurance[b]	.36	.26	.22	.39	.30	.25	.36	.26	.22
Labor[c]	1.04	.69	.52	1.12	.75	.56	1.04	.69	.52
Fuel[d]	1.98	1.98	1.98	1.60	1.60	1.60	2.03	2.03	2.03
Electricity & Miscellaneous	.24	.27	.28	.20	.20	.20	.21	.22	.22
Total	5.57	4.71	4.34	5.17	4.32	3.88	5.60	4.72	4.29

[a] Small, medium, large represent production rate of 500, 750, 1000 gallons of syrup, respectively.
[b] Estimated @ $8/$100 for land and building, Insurance was estimated @ $.75/$100 of original investment.
[c] Charged @ $4/hr for both family and hired labor.
[d] Charged @ $.495/gal. for No. 2 fuel oil, wood @ $40/cord, and LP gas @ $.505/gal.

quired slightly more labor than the oil- and gas-fired evaporators. Labor costs for oil- and gas-fired evaporators ranged from $0.52 to $1.04 per gallon of syrup. The labor cost required for wood-fired evaporators ranged from $0.56 to $1.12 per gallon of syrup, an increase of about 8 percent.

Owner-operator labor was the primary input in the maple processing plant. In general, hired labor is used more for the woods part of the operation than in the actual processing of sap to syrup. Labor other than that of the owner-operator was used least in the filtering and packaging of syrup products; however, these labor inputs are part of marketing costs and were not included in the analysis.

Energy costs. Cost comparisons on the basis of Btu yield showed that LP gas and oil were the most expensive fuels used by producers, accounting for 43.0 and 42.0 percent of the total annual cost, respectively (Fig. 1 and Table 2). Wood was the least expensive fuel, accounting for 37.1 percent of the total annual cost.

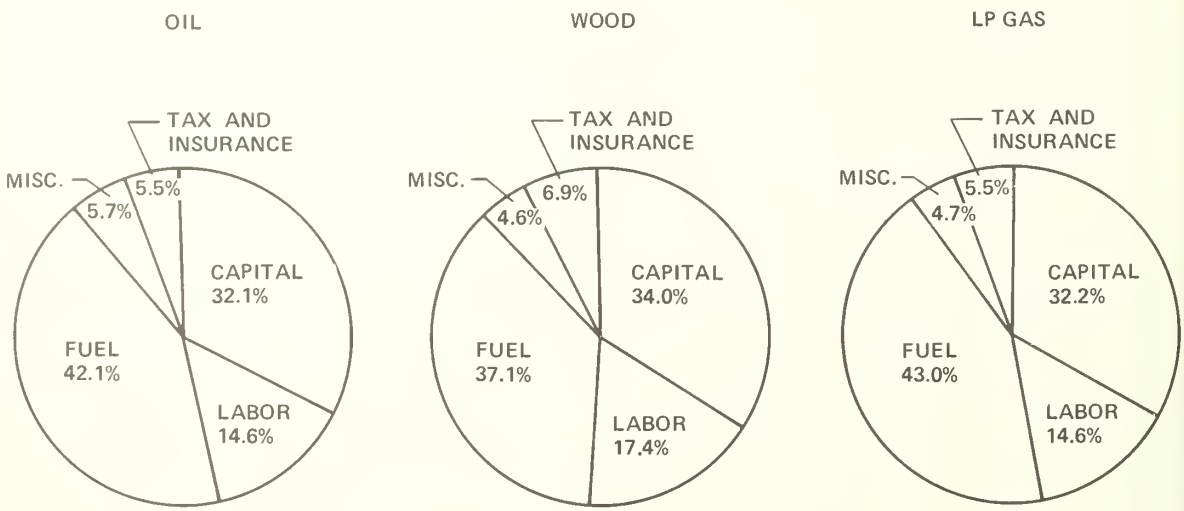

Figure 1.—Percentage breakdown of total costs for three types of fuel used in processing maple sap to syrup in a medium-size (750 gallons of syrup) operation.

The cost of energy in processing maple syrup products relates directly to the efficiency of the evaporation system used. Of the systems studied the wood-fired evaporators operated at between 40 and 50 percent efficiency; efficiency was between 60 and 65 percent for oil-fired evaporators, and between 65 and 70 percent for the gas-fired evaporators.

Energy requirements for processing pure maple syrup are best expressed in a fuel to syrup ratio. In the operations studied, between 3.5 and 4 gallons of No. 2 fuel oil were used to process 1 gallon of syrup. In general, oil used had a higher heat value (HHV)—19,500 Btu per pound. However, this total heat yield was not realized because the oil-fired evaporators operated at only 60 to 65 percent efficiency.

Wood-fired evaporators consumed approximately 1 cord of wood for every 25 to 30 gallons of syrup produced. The wood used had a HHV between 23 and 26 million Btu per cord. These Btu were reduced by moisture content and evaporator design so that only 40 to 50 percent of the total heat input was transferred to evaporated steam.

Gas-fired evaporators consumed approximately 5 gallons of LP gas to produce 1 gallon of syrup. The gas used had a HHV of 91,000 Btu per gallon; of this total, approximately 65 to 70 percent was transferred to evaporated steam.

We calculated the energy cost per gallon of syrup for the three fuel types. The average cost for No. 2 fuel oil at the rate of $0.495 per gallon of oil was $1.98 per gallon of syrup. The average cost for wood at the rate of $40.00 per cord was $1.60 per gallon of syrup; at the rate of $0.505 per gallon, the average cost for LP gas was $2.03 per gallon of syrup (Table 2). If the cost of wood were more than $40.00 per cord, the cost per gallon of syrup for this fuel type would approximate that for oil and gas.

Taxes, insurance, miscellaneous costs

Other costs incurred in maple syrup processing include those for taxes, insurance, electricity, and miscellaneous items. These costs are generally minor in relation to the total cost of operating the plant; that is, together they account for only slightly more than 10 percent of the total annual cost of producing a gallon of syrup. However, they should not be overlooked in the cost of production (Table 2).

Total annual cost

We have seen that the major cost components for the three fuel types in processing sap to syrup are fuel, capital (interest and depreciation), and labor. These components account for approximately 90 percent of the total annual cost. In costs per gallon of syrup, the total annual cost for oil-fired evaporators ranges from a high of $5.57 per gallon of syrup to a low of $4.34 per gallon (decreases as size or production level increases (Table 2). The total annual cost of operating wood-fired evaporators ranges from $5.17 per gallon of syrup to $3.88 per gallon (decreases as production level increases). Costs for gas-fired systems range from $5.60 per gallon of syrup to $4.29 per gallon (Table 2).

Of the evaporators studied, wood-fired evaporator incurred the lowest total annual cost. This is directly attributable to the lower cost of wood used for fuel. But other factors must be considered when using wood—amount of wood required, availability, convenience, etc.

It should be noted that the costs shown in Table 2 are those associated only with processing sap to syrup. To determine the total cost of producing a gallon of syrup, the cost of sap production should be included. As noted earlier, the average annual cost of sap production for tubing systems in 1977 was $3.65 per gallon of syrup equivalent. This includes the cost of capital (interest and depreciation), labor, and costs of fuel, taxes, insurance, and miscellaneous items.

Table 3 shows the sap production cost for a 3,000 tap or 750 gallons of syrup production level

Table 3.—Total costs of manufacturing pure maple syrup for three fuel types (includes both sap production costs and processing costs)[a]

Activity	No. 2 fuel oil	Wood	LP gas
	Dollars per gallon of syrup		
Sap production	$3.65	$3.65	$3.65
Processing[b]	4.71	4.32	4.72
Total cost	$8.36	$7.97	$8.37

[a] Cost figures are for a medium or 750-gallon level of syrup production. Smaller production levels would have a slightly higher total cost and the large—1000 gallon or above—syrup production level would have a slightly lower total cost.

[b] Does not include packaging or marketing costs.

added to the processing cost per gallon of syrup for three fuel types. The No. 2 fuel oil-fired evaporators had a total production cost of $8.36 per gallon of syrup; wood-fired systems had a total production cost of $7.97 per gallon of syrup, and the cost for LP gas-fired evaporators was $8.37 per gallon of syrup. Again, the lower total cost for wood-fired evaporators is directly associated with the lower cost of wood as a fuel.

CONCLUSIONS

The cost analysis of processing maple sap to syrup revealed that:

- The major cost components for three production levels and three fuel types in order of importance were fuel, capital, and labor.
- In 1977, the total annual cost of processing maple sap to syrup for oil-fired evaporators ranged from $4.14 per gallon for larger operations to $5.57 per gallon of small ones; the cost ranged from $3.88 to $5.17 for wood-fired evaporators, and from $4.29 to $5.60 for LP gas-fired evaporators.
- At $40.00 a cord, wood-fired evaporators had the lowest total annual cost; however, at the cost of $50.00 a cord, wood used as fuel would no longer have a cost advantage over oil- or gas-fired evaporators at 1977 prices.
- As the production level increased (larger plant size), the total annual cost of processing decreased, indicating that economies of scale exist in processing sap to syrup. The economic gain was generally related to the cost of capital.
- In 1977, the total cost of production, including sap production and processing costs, for oil-, wood-, and gas-fired evaporators was $8.36, $7.97, and $8.37 per gallon of syrup, respectively.

Since 1974, processing costs have been affected most significantly by the increasing cost of energy. The average price of No. 2 fuel oil rose from $0.18 per gallon in 1971 and $0.24 per gallon in 1974 to $0.495 per gallon in 1977. A conventional oil-fired evaporator requires about 3 1/2 to 4 gallons of fuel oil for each gallon of syrup produced, so the incremental increase in total processing costs since 1973-74 from fuel oil alone is approximately $1.25 per gallon of syrup. This increase is especially significant because energy costs alone accounted for approximately 41 percent of the total cost of processing sap to syrup. From 1974 to 1977, the average farm price for all grades of maple syrup increased by only $1.76, indicating that the price of energy alone is erasing any gain due to the rise in the average market price of syrup.

Capital costs, especially those for plant equipment and building, have increased by an average of 8 percent per year since 1974. This increase also has caused a significant increase in total processing costs, since capital costs account for about 33 percent of the total processing cost.

Farm labor costs have also risen since 1974, but they have not had the same impact on total processing cost as fuel and capital costs. Labor makes up only about 15 percent of the total annual processing cost and, in certain cases, the owner-operator does not charge for his or her labor in the sugarhouse; if there is a charge, it is usually at a lower rate than that for outside labor.

Total annual processing costs have risen by about 9 percent per year since 1974, whereas the average farm price has increased by only about 7 percent per year. This economic fact points to the need for the industry to use all available cost-efficiency improvements that will effectively stabilize or reduce costs. Also, the operator should keep accurate records so that areas of high cost can be pinpointed and effective measures taken to keep those costs in line.

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Reestablishing Understory Plants in Overused Wooded Areas of Maryland State Parks

MAR 26 1979

by Silas Little

and John J. Mohr

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Abstract

In four overused areas, the treatments of small plots were fencing, scarifying the soil, and mulching; fencing and mulching plus planting of shrubs, herbaceous plants, or greenbrier with shrubs or holly. After 3 years, soil compaction was two to four times as great in check plots as in treated plots. Understory cover varied with conditions, but because of volunteer growth, planting was not nearly so important as mulching and eliminating use in reestablishing an understory.

Common and scientific names of plants referred to in this study:

Arrowwood	*Viburnum dentatum*
Ash	*Fraxinus* sp.
Aster	*Aster* sp.
Aster, white wood	*A. divaricatus*
Azalea	*Rhododendron* sp.
Barberry	*Berberis thunbergii*
Beech	*Fagus grandifolia*
Bentgrass	*Agrostis* sp.
Birch, river	*Betula nigra*
Blackgum	*Nyssa sylvatica*
Blueberry	*Vaccinium* sp.
Bluegrass	*Poa* sp.
Cherry, black	*Prunus serotina*
Clover	*Trifolium* sp.
Dogwood	*Cornus* sp.
Elm	*Ulmus* sp.
Fern, Christmas	*Polystichum acrostichoides*
Fern, cinnamon	*Osmunda cinnamomea*
Fern, netted chain-	*Woodwardia areolata*
Fern, royal	*Osmunda regalis*
Fescue	*Festuca* sp.
Fetterbush	*Leucothoe racemosa*
Fleabane	*Erigeron* sp.
Goldenrod	*Solidago* sp.
Greenbrier	*Smilax rotundifolia*
Hickory	*Carya* sp.
Holly	*Ilex opaca*
Inkberry	*I. glabra*
Jewelweed	*Impatiens* sp.
Locust, black	*Robinia pseudoacacia*
Maleberry	*Lyonia ligustrina*
Maple, red	*Acer rubrum*
Maple, sugar	*A. saccharum*
Mountain-laurel	*Kalmia latifolia*
Oak	*Quercus* sp.
Pepperbush, sweet	*Clethra alnifolia*
Pigweed	*Chenopodium* sp.
Pine, loblolly	*Pinus taeda*
Pine, Virginia	*P. virginiana*
Plantain	*Plantago* sp.
Rhododendron	*Rhododendron* sp.
Sassafras	*Sassafras albidum*
Selfheal	*Prunella vulgaris*
Shadbush	*Amelanchier* sp.
Smartweed	*Polygonum* sp.
Spicebush	*Lindera benzoin*
Strawberry	*Fragaria* sp.
Sweetgum	*Liquidambar styraciflua*
Tick-trefoil	*Desmodium* sp.
Violet	*Viola* sp.
Winterberry	*Ilex laevigata*
Wintergreen, spotted	*Chimaphila maculata*
Yellow-poplar	*Liriodendron tulipifera*

Reestablishing Understory Plants in Overused Wooded Areas of Maryland State Parks

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INTRODUCTION

THE USE OF forested recreation areas has increased greatly in the last 30 years in the Northeast. These areas can become so overused that site problems arise, especially near metropolitan centers: Understory vegetation is eliminated, the forest floor may disappear—especially under hardwood stands on slopes—and surface soils become compacted; on slopes, sheet and gully erosion expose the surface roots of overstory trees. These changed site conditions can result in crown dieback or the death of entire stems.

Such problems can be greatly alleviated by limiting the use of areas, restricting visitors to the less critical areas during periods of low use, following a program of rotating use of recreational areas, and channeling visitors to prepared paths, camping pads, or pads for picnic tables. Paths and pads can be covered with wood chips, blacktop, crushed stone, or other materials that reduce erosion and prevent further compaction of the soil. Terraces and steps can be constructed for those portions of paths that are on steep slopes. Paths can be constructed to angle down the slopes, thereby preventing the paths from becoming water courses during wet periods. Barriers of fencing (e.g., snow fencing) or of thorny shrubs and vines might be used to channel visitors to the prepared paths.

Even with restrictions on foot and vehicular traffic, there still remains the problem of restoring understory vegetation in much of the wooded area that will no longer be subject to heavy use. Will the mere exclusion of such traffic be sufficient to allow the invasion of many understory plants, and on what types of sites will this occur? Should soils be broken up by disking, and then mulched? Will planting of suitable vegetation be necessary? If it is needed on some sites, can wildlings (wild plants) be successfully moved from nearby areas not used for intensive recreation?

Because the answers to such questions were not known, the Maryland Park Service and the Northeastern Forest Experiment Station cooperated in a study that was started in 1974. The areas chosen for the study differed in degree of overuse, site conditions, and in the length of time they had been intensively used for recreation. This report summarizes the information obtained in a 3-year period.

LITERATURE REVIEW

Most of the previous attempts to establish a ground cover on the bare soil of overused recreational areas have relied on seeding grasses, often exotic species, and usually on supplemental fertilization. For example, in the Shenandoah National Park no attempt was made to reestablish mountain-laurel, azalea, and other native plants. Instead, gullies were filled with soil, fertilizer was applied and worked into the soil, the area was seeded to K-31 fescue, Merion bluegrass, and common Kentucky bluegrass, and then mulched (Lindsay 1971). Beardsley and Wagar (1971, and with Herrington 1974) also relied on and recommend seeding grasses and clovers.

Sutton (1975) pointed out that exotic plants increase maintenance costs because frequent fertilizing, watering, or pruning may be needed. He thought that the greatest obstacle to the use of native plants was the lack of adequate supplies. Cordell and James (1971) tried to supplement existing vegetation on southern Appalachian recreational sites by planting small, bare-root trees and shrubs. In their study such stock was so susceptible to competition, dry weather and soil, trampling, maintenance mowing, and theft that 83 percent was lost in 3 years, and the average survivor was 23 percent shorter than when planted. Cordell and James thought that planting techniques were not the cause of their poor results. In contrast, Magill and Leiser (1972) considered faulty planting techniques, insufficient or poorly timed maintenance, and lack of protection the chief causes for failure. In New Hampshire, fencing, fertilizing, and liming were not effec-

Figure 1.—A picnicking area near the lake, Greenbrier State Park. Note the absence of both understory vegetation and forest floor. Sheet erosion has occurred and gully erosion has started. Note, too, the occasional stumps left after cutting trees that died.

tive in reestablishing ground cover in heavily used Tuckerman Ravine during a 2-year period (Fay 1975).

Some of the native or introduced species in recreation areas are more resistant. Often these are certain old-field species such as LaPage (1967) studied, or the ones that Bates (1935) and others found were able to survive trampling in England—such as bentgrass, bluegrass, plantain, and clover. Ripley (1962) studied primarily tree species in the southern Appalachians, but did note that mountain-laurel was less tolerant of heavy recreational use than rhododendron and deciduous azalea.

Vegetative deterioration as a result of recreational use varies with edaphic conditions. Settergren and Cole (1970) found that recreation effects were greater on relatively shallow soils with low amounts of moisture than on alluvial or other deep soils. In their opinion, the number and travel of recreationists should be restricted on sites that provide delicate balances for vegetation. Chubb and Ashton (1969) suggested that several factors affect the resistance of vegetation to recreational use: geology and soils (including soil fertility); topography and aspect that affect slope, soil erosion, and the microclimate for flora and fauna; and species, because some are more resistant than others.

In recreational areas, much of the impact on soils may occur in the first 2 years, according to the study by Merriam and Smith (1974). Because Thorud and Frissell (1969) indicated that a compacted forest soil may require up to 6 years to return to its original condition, Merriam and Smith suggested that sites be made resistant to use because rotating sites is not usually feasible in shoreline areas, the most attractive for recreation. Legg and Schneider (1977) found that soil deterioration varied with the intensity of use—there was partial recovery during the winter, but that recovery was less than the amount of deterioration during the previous summer. In urban areas with trees, Patterson (1976) recommended mulching compacted soil with wood chips and other materials; though in urban areas that were grass-covered, lightweight aggregates rotary-tilled into the soil reduced compaction even where soil was under continued recreational use.

STUDY AREAS AND METHODS

Four Maryland areas were selected for our study:

One was in Greenbrier State Park, Washington County, between the turf area near the lake and the uphill parking lots that serve the swimming-picnicking area (Fig. 1). The overstory trees are chiefly yellow-poplar on the lower elevations and oak and hickory on the slope. Soils are in the Edgemont and Hazel series. Since 1968 when the area was opened for recreation, use has been so heavy that by 1974 both forest floor and understory plants had mostly disappeared, and some sheet erosion on the slopes had exposed surface roots of the trees.

A second area was in the Manor Area of the Cunningham Falls State Park, Frederick County, and has been used for picnicking since 1961. Much of the area is in a cove, and soils are deeper than in Greenbrier State Park, but they are in the Edgemont or Edgemont-Chandler series. For the most part, this area had been so heavily used that there was no understory vegetation. However, in most portions there is little or no slope, so soil erosion has not been common.

Our third site was the Lake Area, Cunningham Falls State Park, which was opened to swimming and picnicking on July 4, 1974. Picnic tables were installed under an oak—yellow-poplar stand near the swimming area and under a yellow-poplar stand farther away. The understory vegetation was cut before the area was opened to the public, and most of the plants were severely trampled during the first season, especially in the stand closest to the swimming area. Recreation here is concentrated in areas that are somewhat flatter than those used at the Greenbrier site. Soils are in the Highfield series.

The fourth area was at Milburn Landing, Pocomoke River State Park, Worcester County. This area has been used for camping since 1955. It is a relatively flat, Coastal Plain site on soil of the Matapeake series. The understory of a pole stand of loblolly pine had been cut, allowing campers to drive vehicles between the trees in much of the area. The vehicular

and foot traffic had eliminated many understory plants, although close inspection showed that some small herbaceous plants and a few woody plants were still present, especially near overstory stems.

Within each of two blocks in each area, five 10-foot-square (3-meter) plots were established. Four plots in each block were treated and enclosed by a fence. One untreated plot was a check and was not fenced. The four treatments were:

(1) Native perennial, nonwoody plants were planted and lightly mulched. The plants were dug from nearby wooded areas, and 10 to 13 plants or clumps were set out in each plot. In all areas the plants included ferns, grasses, sedges, and forbs, but specific species varied among the areas. Wood chips were lightly sprinkled over the whole area of each central Maryland plot, while oak-bark chips were used in the Milburn Landing plots.

(2) Native shrubs were planted and lightly mulched. In each plot 10 to 12 clumps were transplanted from nearby wooded areas. The species were low-bush blueberry, mountain-laurel, azalea, and dogwood in the Greenbrier plots; mountain-laurel, azalea, and low-bush blueberry in the Manor plots; spicebush, mountain-laurel, and arrowwood in the Cunningham Falls lake plots; sweet pepperbush, winterberry, maleberry, mountain-laurel, inkberry, blueberry, shadbush, azalea, fetterbush, and arrowwood in the Milburn Landing plots. Mulching here (and in treatments 3 and 4) was similar to treatment 1.

(3) A mixture of greenbrier and shrubs or slow-growing trees were planted and lightly mulched. In each plot five or six clumps of greenbrier were planted, along with four to seven other woody plants. The latter were mountain-laurel, blueberry, and dogwood in the Greenbrier plots; barberry and mountain-laurel in the Manor plots; mountain-laurel, spicebush, and barberry in the Cunningham Falls lake plots; and holly in the Milburn Landing plots.

(4) Plots were scarified and lightly mulched. In this treatment the surface soil was broken up, usually with a fire rake.

Plots at Cunningham Falls and Greenbrier State Park were established in October 1974; the Milburn Landing plots, in November 1974.

The plots were examined in September or early October of each of the 3 subsequent years. The plot cover of woody, herbaceous, and all understory plants was estimated to the nearest 5 percent. The number of seedlings or clumps of each woody species was recorded by species, and an attempt was made, unsuccessfully in thick covers, to do the same for herbaceous plants.

In 1975, with a double-ring infiltrometer, an attempt was made to determine the rate of infiltration. However, the results were so variable that it appeared necessary to make a number of tests for valid comparisons, which would have greatly disturbed the conditions within the plots.

Hence, penetrometer readings were substituted, and several measurements, often 10, were made in each plot. The pocket penetrometer has a retracting piston that penetrates the topsoil under pressure, and the amount of pressure required to insert the piston is recorded in tons per square foot. Its range is from 0 to 4.5 tons. Ward and Berg (1973) used the pocket penetrometer to study soil compaction in Michigan's Waterloo Recreation Area. They reported that readings in excess of 3.0 tons denoted areas of heavily compacted soils.

RESULTS

Soil compaction

The exclusion of recreational use, mulching, and scarification were highly effective in improving surface soil conditions within 3 years. In 1977 penetrometer values showed that in all blocks the check plots had soils two to four times more compacted than the plots fenced, mulched, and scarified or planted in 1974 (Table 1).

Woody understory plants

Woody understory plants formed very little cover, usually about 0 percent, in check plots in 1977 (Table 2) and often only similar amounts in fenced plots with unfavorable conditions—heavy shade, relatively heavy deposits of soil or wood chips from washing, thick leaf litter from blowing or washing. In con-

Table 1.—Average penetrometer values in 1977 for check and treated plots by area and block (in tons/square foot)

Area	Block	Check plot	Treated plots
Pocomoke River			
Milburn Landing	A	3.70	1.19
	B	4.43	1.19
Cunningham Falls			
Manor Area	A	2.85	1.44
	B	1.35	0.33
Lake Area	A	2.75	0.77
	B	4.5	2.02
Greenbrier	A	4.5	1.38
	B	3.85	1.69

trast, woody plants provided covers of 20 to 40 percent in eight plots (four at Milburn Landing, three in one lake block at Cunningham Falls, and one at Greenbrier). In general, these covers developed in the most favorable conditions: deep soils under relatively light shade. Much of the cover here came from volunteer woody plants, as shown by the fact that two of these eight plots received no planted shrubs (Table 2).

The survival and growth of transplanted woody plants varied with species (Table 3). Again, area had an appreciable effect. Survival was 81 percent in both Milburn Landing blocks, 81 percent in one Cunningham Falls lake block, 81 and 91 percent in the Greenbrier blocks, but only 48 to 75 percent in the three other blocks. On the deep Coastal Plain soil and under the light shade at Milburn Landing, several of the transplanted shrubs (especially winterberry, sweet pepperbush, fetterbush, and azalea) were thriving in 1977, and one winterberry was 5.3 feet tall. In contrast, most of the shrubs moved into the Manor Area were placed under heavy shade, and those in one block were subjected to deposits of leaves, wood chips, and soil from washing. As a result, while six of the seven barberries planted there were still alive, only two were classed as thriving.

Tree reproduction increased in the fenced plots. In 1977 the average number of tree seedlings in treated plots was about 14 times that in the unfenced check plots (Table 4). However, there were great differences among plots. Nine treated plots had only 2 to 5 seedlings, while 11 plots had 21 to 46. Treated plots in one Milburn Landing, one Cunningham Falls, and one Greenbrier block tended to have a high number of tree seedlings (Table 4). Species varied greatly with area. At Milburn Landing the seedlings were red maple, sweetgum, yellow-poplar, loblolly pine, river birch, black cherry, oak, blackgum, and holly. In the other areas they often included yellow-poplar, red maple, black locust, oak, and sassafras, while black cherry, ash, Virginia pine, blackgum, elm, hickory, beech, and sugar maple seedlings were found in only one to three blocks.

Table 2.—Cover of woody understory plants in 1977 by area, block, and treatment (in percent)

Area	Block	Check	Fenced and:			
			Scarified, mulched	Herbs planted, mulched	Shrubs planted, mulched	Barrier plants planted, mulched
Pocomoke River						
Milburn Landing	A	0	5–10	25	40	10
	B	0	15	5	30	20
Cunningham Falls						
Manor Area	A	0	0+	0+	0–5	5–10
	B	0+	5	0+	5	10
Lake Area	A	0–5	5–10	5	15	15
	B	0	30	0+	20	40
Greenbrier	A	0	0+	0+	5	0–5
	B	0	0+	0	20	5

Table 3.—Survival of transplanted woody plants in study areas over 3 years

Species	Transplanted plants	
	Number	% survival
Shadbush, inkberry, winterberry	4	100
Spicebush	15	93
Fetterbush, maleberry, sweet pepperbush	12	92
Azalea	11	91
Barberry	8	88
Holly	8	88
Dogwood	7	86
Greenbrier	43	72
Mountain-laurel	41	63
Blueberry	16	56
Arrowwood	2	0

Table 4.—Number of tree seedlings per 10-foot-square plot in 1977 for check and fenced plots by area and block

Area	Block	Check	Fenced plots
Pocomoke River			
Milburn Landing	A	0	24
	B	0	13
Cunningham Falls			
Manor Area	A	2	11
	B	2	10
Lake Area	A	0	4
	B	2	27
Greenbrier	A	3	29
	B	0	6

Herbaceous plants

Herbaceous covers were more quickly favored than woody covers. By 1977 the herbaceous covers in 11 fenced plots, all with favorable growing conditions, were 50 to 80 percent (Table 5). Of these plots, only four were planted to herbaceous plants, so volunteer growth was responsible for much of the cover—even in plots where such plants were moved in. In contrast, under the adverse growing conditions, herbaceous covers were 0 to 15 percent in all plots at Greenbrier, in one Manor block, and in most check plots.

The volunteer growth that came in after plots were fenced obscured the survival and growth of some of the transplanted herbaceous plants because the locations of the latter were mapped, but not marked. Ferns were moved with a relatively high degree of success: 72 percent were living after 3 years. Under favorable conditions all ferns survived and were thriving in 1977, whereas in one Manor Area block survival was only 25 percent because washing covered the other ferns with leaves, wood chips and soil. However, in no area had the ferns spread. Such species as the cinnamon fern, royal fern, and netted chainfern were successfully transplanted at Milburn Landing, and the Christmas fern in the other areas.

The success of transplanting other herbaceous plants varied: it was sometimes good under favorable conditions, but always poor where the plants were subsequently covered

Table 5.—Herbaceous cover in 1977 by area, block, and treatment (in percent)

Area	Block	Check	Fenced and:			
			Scarified, mulched	Herbs planted, mulched	Shrubs planted, mulched	Barrier plants planted, mulched
Pocomoke River						
Milburn Landing	A	30	75	50	15	80
	B	10	35	75	50	50
Cunningham Falls						
Manor Area	A	0	0	10	0	0
	B	0	25	20	25	5
Lake Area	A	0	65	50	75	75
	B	0	25	80	45	35
Greenbrier	A	0	15	15	0–5	0+
	B	0	0	0+	0+	0+

with a thick layer of leaves, soil, or wood chips. For example, in one Manor Area block where washing was not a factor, both plants of spotted wintergreen survived; in the other block, neither plant survived because of the deposits from washing. However, certain subshrubs such as spotted wintergreen, some species of ferns, and some other herbaceous plants are better adapted to growing under moderate to heavy shade than many understory species.

Under favorable light conditions, sediment deposits favored certain volunteer herbaceous plants. As might be expected, these included smartweed, jewelweed, and pigweed.

Species of volunteer herbaceous plants were numerous and varied with area. Some of the forbs were weeds such as selfheal, plantain, and tick-trefoil. Other forbs of possible interest to recreationists included wild strawberries, violets, goldenrod, fleabane, and asters. In the fenced plots of the lake area of Cunningham Falls State Park, the white wood aster was the most common volunteer forb, and along with the goldenrod provided a show of contrasting color in September and October.

General understory conditions

By 1977, 3 years after treatment, the understory cover greatly increased in many of the fenced plots (Fig 2, Table 6). On the deep Coastal Plain soil of Milburn Landing, all treatments that included fencing then had covers of 65 to 77 percent, more than three times as much as in the checks. There were similar results at the lake area of Cunningham Falls State Park, while the effects of treatments were much less in the Manor Area and at Greenbrier (Table 6). Relatively dense shade in the Manor blocks, washing and deposits of wood chips or soil in one Manor block, and a heavy cover of leaves in one Greenbrier block were the apparent causes for the reduced cover.

Figure 2.—A 1977 view of one of the Milburn Landing blocks. Note the understory cover inside the fence, and lack of it outside.

Table 6.—Cover of understory plants by treatment and year for Pocomoke River, Cunningham Falls, and Greenbrier areas (in percent)

Treatment	Milburn Landing			Manor Area			Lake Area			Greenbrier		
	1975	76	77	75	76	77	75	76	77	75	76	77
Check (unfenced)	30	30	20	0	0	0	6	3	1	0	0	0
Scarified, mulched	38	65	65	2	2	13	25	42	62	3	5	10
Herbs planted, mulched	42	60	77	3	6	15	52	70	65	10	8	8
Shrubs planted, mulched	37	58	68	3	8	15	52	72	75	7	7	14
Barrier plants planted, mulched	52	68	75	5	8	11	50	63	82	7	6	5

CONCLUSIONS

In general, even though some wildlings were successfully moved, the emphasis in reestablishing understories in overused recreational areas should apparently be on confining recreational use to prepared paths and pads through the use of fencing or other barriers, and mulching portions outside of the paths and pads. Scarification before mulching seems questionable in wooded areas because it may damage tree roots—even though it would help to break up the compacted surface soil. Mulching and the exclusion of use allow the invasion of many volunteer plants under favorable growing conditions, hence transplanting seems desirable only where rapid establishment of understory plants is desired. If high survival is desired, transplanting should be restricted to favorable sites—those with light shade, deep and moist soils, and no washing. Also, transplanting should be limited to species that in our trial were moved with a high degree of success—such as spicebush and sweet pepperbush among the shrubs, or Christmas fern among the herbaceous plants.

The establishment of plants that might serve as barriers to foot traffic was sufficiently poor that fences seem to be the best solution until improved survival and growth are ensured. Holly, greenbrier, and barberry can be moved with a fair degree of success, but even under favorable conditions in our trials, their growth was so slow that they offer little promise of forming suitable living barriers within a reasonable time.

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Abstract

The production of opportunities for high-quality visitor experiences is a basic goal of recreation management. Recreation quality can be interpreted using concepts from psychological field theory to relate emotion to the strength of motivation. Applications to on-site management for recreation quality and use regulation are suggested.

INTRODUCTION

THE PRODUCTION of opportunities for high-quality recreation experiences is a basic goal of all recreation managers and a major and growing responsibility of foresters and other land managers (Driver and Brown 1975; Schoenfeld 1968). Unfortunately, this management objective has proved elusive; after all, just what are "high-quality experiences," and how can we produce them? Wagar (1966) emphasized the importance of providing a range of facilities and opportunities to meet a variety of human needs. Others have suggested a relationship between quality and variation in the environment (More, et al. 1977) or have attempted to define quality in terms of the values of participants in an activity (Hendee et al. 1968; Shafer and Meitz 1969).

In recent years, however, perhaps the most widely used conception of recreation quality has been that of satisfaction. Here, recreation visitors are treated as customers whom management attempts to satisfy, and their satisfaction is treated as a major output of the recreation system. In any given activity, people tend to seek multiple satisfactions (Hendee 1974), but the types they seek may differ for different types of participants. Generally, the *amount* of satisfaction an individual receives from a particular experience reflects the degree of congruence between that person's expectations and the perceived reality of the situation (Rogenbuck and Schreyer 1977; Peterson 1974; Bultena and Klessig 1969).

But what, really, is satisfaction? Perhaps it is best described as a *feeling* that people have when their needs have been met. But as a feeling, it is one of a broader group of emotions, many of which may be important in recreation (More and Payne 1978); fun, joy, pleasure—these and others are significant emotions that our research frequently neglects. Moreover, we have tended to think of satisfaction as the outcome of an experience without considering the process involved in generating total satisfaction, or how satisfaction and other feelings may vary over the entire course of an experience. In this paper, we attempt to interpret recreation quality in terms of the emotional aspects of experiences, and to show how these can be modeled using concepts from psychological field theory (Lewin 1951) and expectancy-value theory (Atkinson 1964). This should enable us to incorporate many of the ideas expressed in satisfactions research into a broader, more explicit framework. After describing the theoretical constructs, we suggest some ways in which it might prove useful in managing recreation quality.

THEORETICAL CONSTRUCTS

Application of the theoretical framework to management problems requires an understanding of the goals of users and how these goals influence behavior. The term "goal" can be defined at several levels. For example, one goal of a mountain climber might be to obtain vigorous exercise. The goal of a wilderness user might be to spend time in an unchanged natural environment. These high-level goals (or motives) are important determinants of the types of experiences sought (Driver and Brown 1975). At a lower level, goal can be defined as a specific site that will attract users and which they will strive to reach. In this terminology, the goal of a mountain climber is to reach the summit. When he arrives there, his next goal may be to return to the spot where he left his car. Similarly, the goal of a wilderness user may be to reach his next camping site.

While higher order goals are a major determinant of recreation use, most of this paper

is concerned with goals as physical sites. Forested recreation areas offer a variety of sites that serve as potential goals. There can be facilities such as visitor centers, trail shelters, trail heads, historic sites, and picnic sites. There are also many natural goals—for example, lakes, caves, mountain summits, scenic overlooks, and waterfalls.

To a visitor about to enter a recreation area, each of these goals has some emotion attached to it. The nature and extent of that emotion depends on how motivated a person is to attain that goal. This, in turn, depends on such factors as past experiences and the information available about the goal. Thus, feelings about going into a cave may vary from intense excitement to fear to indifference. Understanding how people feel about particular goals, and how these feelings vary over time and space, provides a basic framework for both enhancing user experiences and regulating the amount of use a particular goal receives.

Two assumptions underlie the application of our theory to problems in recreation:

1. The quality of an experience will be higher if the total amount of positive emotion (fun, excitement, pleasure, satisfaction) a user feels during the experience is increased.
2. The amount of emotion (positive or negative) is determined by the strength of a person's motivation; that is, the stronger the motivation, the greater the emotion.

Motivational strength is the basic variable in our model and it can change over time and space. In some cases, it may be inferred from actual behavior; the vigor of a behavior is a good indication of the strength of a person's motivation (Atkinson and Birch 1970). For example, if two people, one walking and one running, are approaching a fishing hole, we might infer that the runner is moved by a stronger force than the walker. Further, other things being equal, we would expect that the two people would *feel* differently about reaching the site as well, with the runner being the more excited of the two. Thus, these assumptions taken together imply that to increase the amount of positive emotion a person feels, increase the strength of his motivation.

The basic equation for estimating the strength of motivation (adapted from Lewin 1951) at any given moment is:

$$M = \frac{A(G)}{d_{p,g}} \qquad (1)$$

where:

M = the strength of the motivation;
A(G) = the attractiveness of a particular goal G; and
$d_{p,g}$ = the psychological distance of the person (p) from the goal (g).

One can think of attractiveness on a scale of −100 (for a goal that is maximally unattractive) to +100 (for a goal that is maximally attractive). Motivational strength (M) covers the same range. If a goal is very unattractive, M will be negative, and the person will try to avoid the goal (place). For very attractive goals, M will be positive, and the person will try hard to reach the goal.

The actual attractiveness of a particular goal depends upon both the attributes of the goal and the attributes of the users. In expectancy-value theory (Atkinson 1964) the attributes of the goal form expectations—subjective probabilities or beliefs about the extent to which a goal posesses these attributes. These expectations range from 0, when there is virtually no possibility that a goal posesses a certain attribute, to 1.0, when there is absolute certainty that a goal posesses the attribute. Thus, we may have learned that when a site is designated a picnic area, there is a very good chance (expectation = 0.9) that it will have picnic tables.

While we may expect a goal to posess a particular attribute, this does not necessarily mean that it is especially valued. To continue the picnic area example, some families may not care if tables are present, preferring to spread a blanket on the ground. Values are the attributes of the person important in determining attractiveness. They reflect both the immediate, short-term needs of the person, as well as his long-term motives—the higher order goals mentioned previously. Thus, how much a person wants to go camping de-

pends both upon the long-term motives that affect camping and the nature of the immediate situation.

Values can be positive or negative; one might think of them as ranging from plus 10 to minus 10. They are paired to individual expectations in a multiplicative relationship. Moreover, values, as used here, are roughly analagous to the "satisfactions" we described. Consequently, any given goal is likely to be associated with a number of values, and the sum of the individual expectation/value pairs will determine the attractiveness:

$$A(G) = \sum_{i=1}^{n} E_i V_i \qquad (2)$$

where:

A(G) = the attractiveness of goal G
E = an individual expectation
V = an individual value

To illustrate, imagine a family conversation: "Let's not go there—it'll probably be crowded; besides, it looks like it might rain later today." "Oh, but it's such a pretty spot; we could use the exercise and I think the kids would really enjoy it." Given arbitrary values, the conversation implies 5 attributes with expectancy/value pairs:

Attribute	Expectation (probability)	Value	E_iV_i
Person 1			
Crowding	.5	−7	−5.6
Rain	.3	−9	−2.7
			−8.3
$A(G) = \sum_{i=1}^{n} E_iV_i$			
Person 2			
Aesthetics	.7	+10	+ 7.0
Exercise	.6	+ 4	+ 2.4
Please Children	.5	+ 5	+ 2.5
			+11.9
$A(G) = \sum_{i=1}^{n} E_iV_i$			

Thus, there are two very different attractiveness ratings for the same site. As discussion about the site continued, both people would probably modify their initial attractiveness ratings until some decision could be reached.

By substitution, then, the equation for determining the strength of motivation becomes:

$$M = \frac{\sum_{i=1}^{n} E_iV_i}{d_{p,g}} \qquad (3)$$

Psychological distance refers to a person's subjective estimate of the time required to reach a goal (Atkinson 1964). Psychological distance is related to, but distinct from, physical distance because the time required may reflect other factors like fatigue, frustration, and monetary costs. Thus, two people may perceive the same stretch of physical distance in very different ways. However, for the purpose of this exposition, we assume an average walking or driving time to a goal can be calculated for a particular population of visitors. Indeed, this idea is very similar to the average times already given in many roadmaps or trail guides.

To illustrate the relation among strength of motivation, attractiveness, psychological distance, and emotion, suppose you are taking a child to a beach that is an hour's drive from home. The child's goal is the beach, and because beaches are generally attractive to children, we assume that A (beach) = +100 (we also assume that the A (beach) does not change during the trip). As we start out, there are 60 minutes to go, so the strength of motivation is:

$$M = \frac{100}{60} = 1.66$$

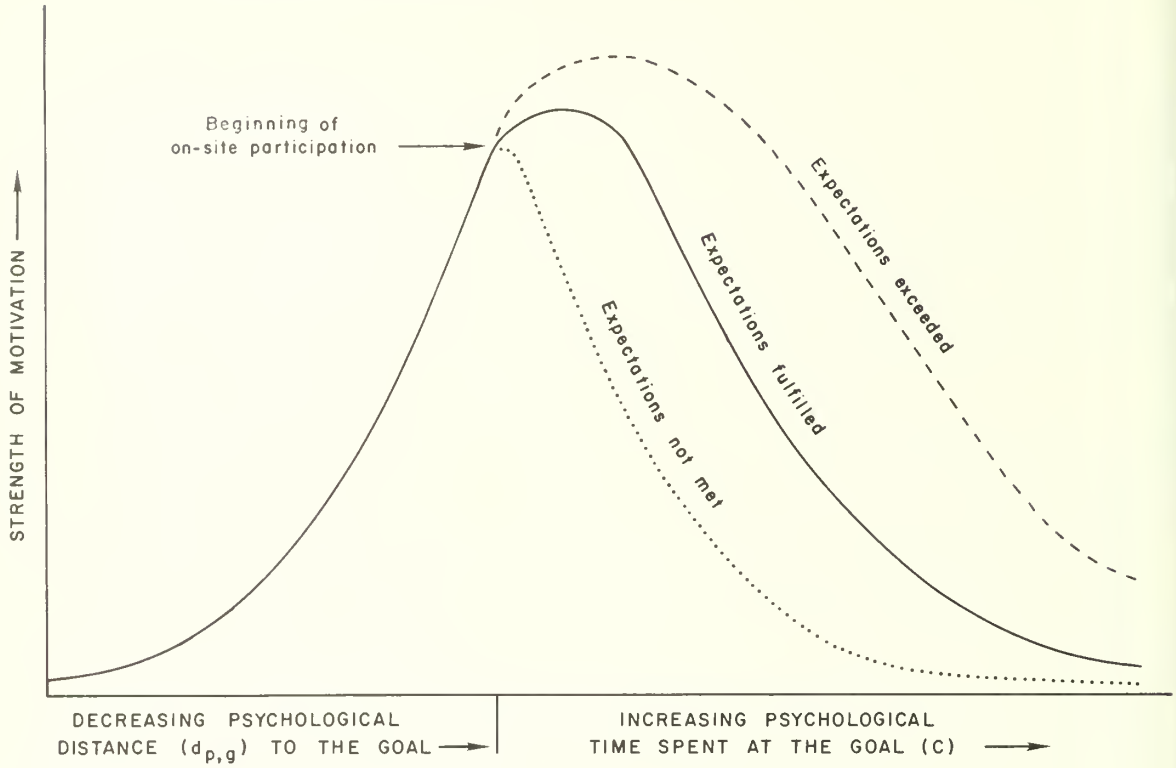
When halfway there,

$$M = \frac{100}{30} = 3.33$$

and the child is becoming excited. Finally, upon arriving in the parking lot,

$$M = \frac{100}{1} = 100.0$$

Figure 1.—Strength of motivation (and emotion) throughout a recreational experience.



the child is so excited that he may break into a run to cover the last few feet to the shore.

Since most adults have had far more experience with beaches, the A (beach) might be a lot lower. Consequently, the motivation and excitement would be less. Despite these individual variations, it should be possible to compute a mean attractiveness for a population of users by using a standard questionnaire and sampling techniques.

Of course, most of the fun of an experience comes during participation after a person has reached the goal and has begun to participate. Here, a complex set of processes take over. Psychological distance is no longer a factor since the goal has been attained. Similarly, expectations are superseded by reality.

What, then, happens emotionally during the remainder of the experience? Thus far we have been dealing with the emotions generated by anticipation. When the person arrives on-site, anticipation ceases and consummation begins. Generally, during this consummation period, the strength of motivation will begin to decline after a short lag period (a sort of "oh boy, we're here" period carrying over from anticipation), and it will continue to decline asymptotically toward zero until the person reaches a point where the strength of motivation for an alternative activity becomes dominant and the person makes the decision to leave (Atkinson and Birch 1970). This decline in motivation is accompanied by a corresponding decline in positive emotion (More and Payne 1978).

Like distance, psychological time spent at a goal is only partially determined by actual time. For instance, if a goal turns out to be disappointing, the psychological time spent may increase rapidly, causing motivation level to decline quickly (dotted line in Figure 1). However, when a goal exceeds expectations, a person may be so involved in participation that he is unaware of the passage of time. In this

case, C would increase very slowly, causing M to decline much more slowly (dashed line in Figure 1).[1]

No matter how attractive a goal is or how greatly it exceeds expectations, eventually the motivation to move on to another goal will become greater than the strength of the motivation to remain, and the person will make the decision to leave. Thus, the duration of the experience will be influenced by the initial attractiveness of the goal (the higher the attractiveness, the longer the duration and vice versa), how well the goal meets expectations, and the strengths of other motivations acting upon the person (Atkinson and Birch 1970). Finally, the decline in motivation is accompanied by a decline in positive emotion (More and Payne 1978).

While the decline is inevitable, the rate at which it occurs is variable and depends upon how well the goal/site meets a person's expectations about it. There are three possible outcomes for this situation (Fig. 1). First, a site or activity may be exactly what a person expected. If so, strength of motivation should follow the general path outlined above, declining until it is replaced by an alternate motivation toward another goal. A second possibility is that the goal/site will turn out to be disappointing—it will not measure up to a person's expectations. In this case, the motivation will decline rapidly and the person may depart sooner that he had anticipated. Finally, when a goal exceeds a person's expectations, motivation will decline more slowly, perhaps prompting the person to participate for a longer period.

Consummation may be expressed within the theory as the psychological time a person has spent at the goal. This is expressed in a parameter C added to psychological distance and defined in such a way that if $d_{p,g} > 0$, $C = 0$ or if $d_{p,g} = 0$, $C > 0$. Thus, the equation for determining the strength of motivation at any given point over the entire experience becomes:

$$M = \frac{\sum_{i=1}^{n} E_i V_i}{d_{p,g} + C} \qquad (4)$$

where C is the consummation parameter.

In summary, attractiveness, psychological distance, and consummation all play important roles in determining the quality of a particular recreational experience. Understanding how these factors contribute to the process of generating emotions during recreation can provide a useful insight into the very nature of these experiences. In the remainder of this paper we discuss some ways in which these concepts might be applied to influence recreation quality and the amount of use a particular site receives.

MANAGING FOR ATTRACTIVENESS

If attempting to improve the quality of the visitor's experience is a major objective of recreation management, then one way to capitalize on this theory is to try to increase the positive attractiveness of a goal. Suppose a management practice raises the attractiveness of a goal from +20 to +40, while the psychological distance remains the same (Fig. 2). All things being equal, the total area under each curve represents the amount of positive emotion or excitement that the person experiences while approaching the goal. Therefore, the difference in area between the curves indicates the extent to which the quality of this phase of the recreational experience has been improved by increasing the positive attractiveness of the goal.

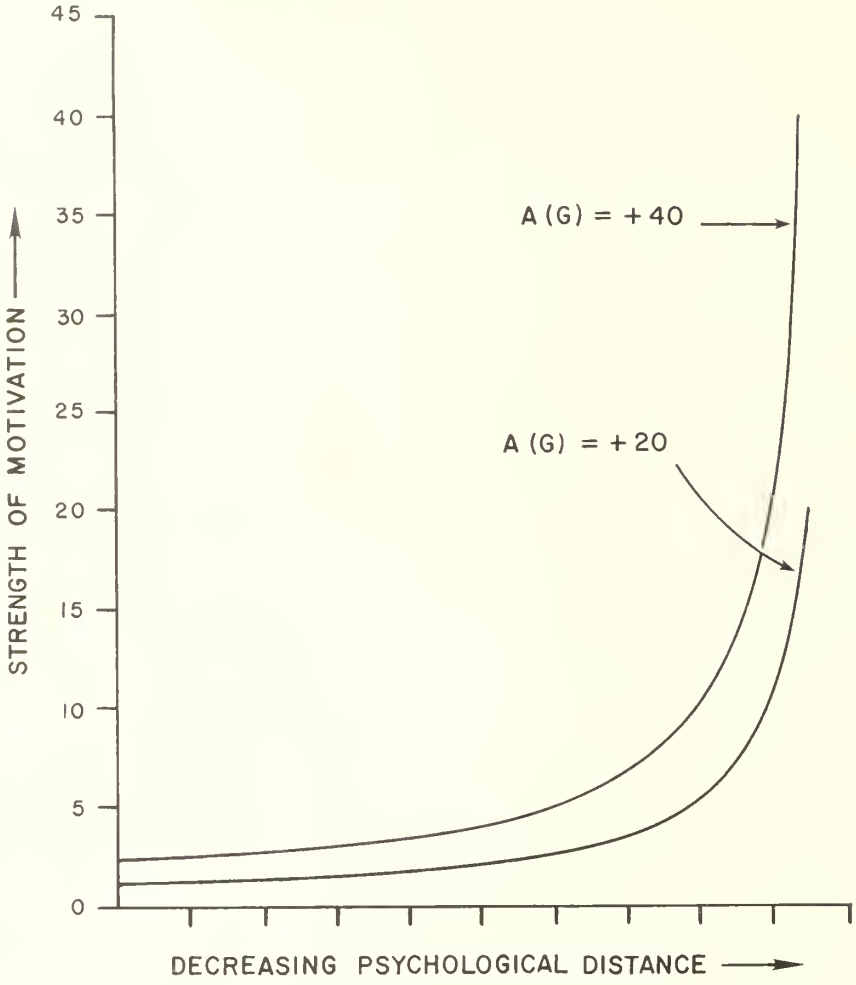
Recall that the attractiveness of a goal depends on attributes of both the user and the goal. One major user attribute that influences attractiveness is the higher order goals or

[1]A mathematical description of these changes is as yet uncertain. One possibility is that M might take a shape similar to the gamma distribution:

$$M = f(X) = \begin{cases} KX^{\alpha-1} e^{-(X/\beta)} & \text{for } X > 0 \\ 0 & \text{for } X \leq 0 \end{cases}$$

where α and $\beta > 0$ and K is a normalizing constant. Unlike the probability distribution, the area under the motivation (M) curve need not sum to 1 so K is simply a constant (not necessarily a *normalizing* parameter). Also, in this context, X would be regarded as a continuous variable representing psychological distance with values becoming negative during consummation.

Figure 2.—Strength of motivation for two goals, A(G) = +20 and A(G) = +40, over the same psychological distance.



motives mentioned above. These motives may be important determinants of the demand for a specific lower level goal (Driver and Brown 1975). For example, people who are motivated by a desire for solitude may select different types of campsites than people with strong social motives. Or a rough trail to a mountain summit may prove more attractive to visitors with strong achievement and exercise motives than a gently sloping, short, interpretive trail.

In most on-site management operations, however, it is nearly impossible to control the attributes of the users except through long-term advertising, education, or communication programs. Therefore, management can focus on attributes of the goal. Often, user preference surveys show what attributes are important. For example, some trailer campers desire flush toilets and hot showers (Bond and Ouellette 1968). For these people, a campground that provides these conveniences will be more attractive than one that does not. Similarly, a lake staffed by lifeguards may be more attractive to a mother with small children than one offering only unsupervised swimming. Creating a scenic vista from a mountain summit will probably increase the valence of the mountain top as a goal.

Peterson (1974) classified many such attributes by the way in which they contribute to the satisfaction of wilderness users in the Boundary Waters Canoe Area. There are four such classes of attributes: desirable overperformers (having to wash in cold water, using bug sprays), undesirable overperformers (biting insects, damaged birch trees, use of motors), desirable underperformers (catching big fish, beaver dams and lodges, clear lakes and streams), and undesirable underperformers (mechanized portages, fences). By understanding these attributes and how they contribute to satisfaction, managers can enhance the attractiveness of a site.

Another attribute of a site that might be manipulated is its name. For example, in the Mount Rogers National Recreation Area, the name of a point was changed from "North End of Wilburn Ridge" to "Rhododendron Gap." Almost immediately the area went from virtually no use to problems of overuse (Keith Argow, personal communication 1978). The name change apparently increased the attractiveness of this point as a goal for recreationists, probably by changing people's expectations of what could be found there.

This increase in attractiveness also may result from changes in land classification or designation. Reed (1973) found differences in people's "prestige" ratings of land classifications (for example, National Parks and State Forests), and suggested that prestige levels could be an important factor affecting visitation rates.

In general, the management of information to modify expectations seems a particularly promising technique. For instance, Lime and Lucas (1977) mailed information about use patterns in the Boundary Waters Canoe Area to people who had registered there in past years. Preliminary analysis of the data has indicated that people definitely made use of this information in planning subsequent trips. In theoretical terms, the attractiveness of some sites was reduced because of the increased expectation of crowding (a negative value), while the attractiveness of others was increased due to increased expectations of solitude.

As noted above, many users have different motives for visiting a particular site, and what attributes of the site can be successfully manipulated will depend on these motives. The attributes mentioned here reflect some of the possibilities. Creative managers will doubtless be able to think of more that are appropriate to the activities and user groups with which they deal.

MANAGING FOR PSYCHOLOGICAL DISTANCE

The management implications of psychological distance are less obvious, but quite important nevertheless. Recall that psychological distance refers to subjective estimates of the length of time required to reach the site, and that strength of motivation (and excitement) increases as the psychological distance decreases—again assuming that A(G) does not change during travel.

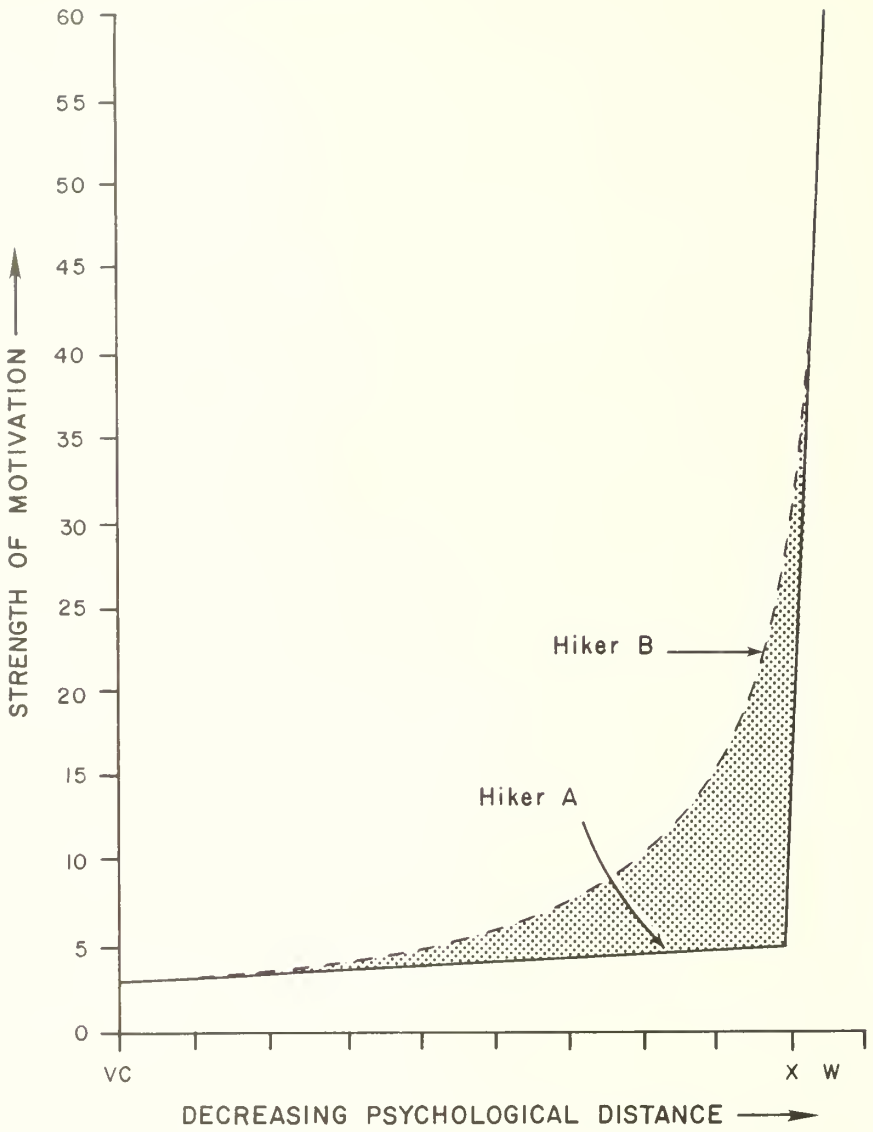
The difficulty is that people who are hiking, riding, or driving through a forest may not have a good idea of where they are in relation to a site. As a result, they may be unable to make accurate estimates of the distance.

Two possible outcomes for this situation are: people will overestimate the remaining distance, and believe they have farther to go than they actually do; or they may underestimate the remaining distance, believing that they are closer to the goal than they really are. The first situation may lead to a mild surprise as the people stumble out onto the goal. The second can lead to frustration and disappointment. Both of these outcomes can detract from the quality of the experience.

To graphically illustrate the effects of overestimating distance, suppose two people are at a visitor center (point VC in Figure 3). A waterfall, point W, is equally attractive to both of them (A (waterfall) = 60) and both decide to go. The average walking time from the visitor center to the waterfall is 20 minutes.

Hiker A is visiting the area for the first time. As he walks along, he loses track of time and fails to realize how far he has come (thus overestimating the remaining distance). He may

Figure 3.—Effect of overestimating psychological distance.



begin to have a vague idea that he is getting closer because he has been hiking for some time. This vague idea is represented by the gradual increase in the strength of the motivation that is acting on him (solid line). Eventually, he hears the sound of the fall (point X), which indicates that he is nearly there. From this point on, the force increases rapidly until he reaches the fall, and

$$M = \frac{60}{1} = 60$$

Hiker B, on the other hand, is very familiar with the trail. As a result, he always knows where he is and is able to make accurate estimates of distance. The increase in motivation that he experiences as he gets closer to the waterfall is shown by the dashed line.

Of course, both of these people end up with M = A (waterfall) = 60, and derive pleasure from being there. However, the crucial point, according to this theory, is that the difference between the two curves (the shaded portion of Figure 3) represents the amount of excitement

or pleasure lost to Hiker A simply because he had no idea where he was.

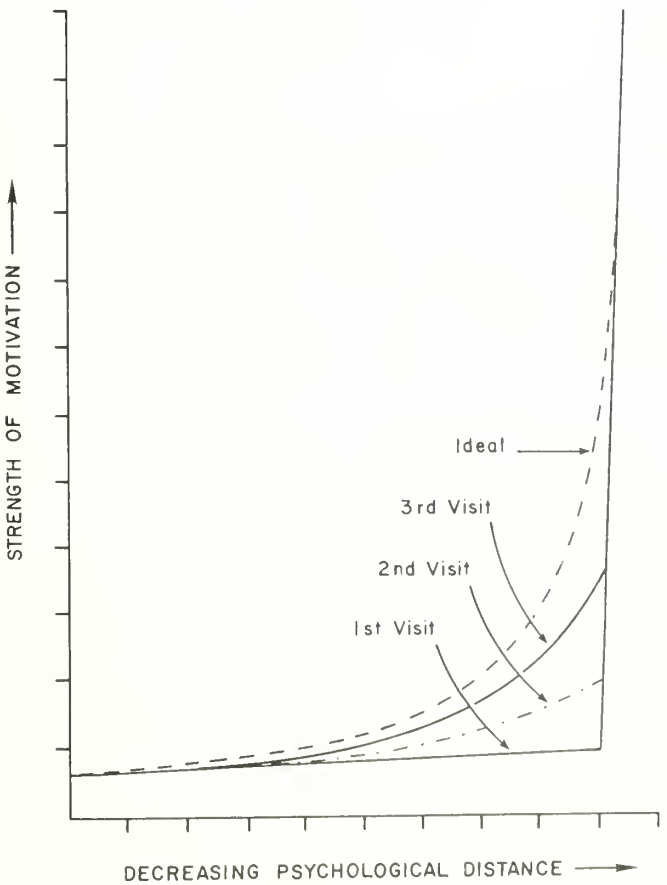
The curve for Hiker B is, naturally, an ideal curve because it is based on perfect knowledge of distance. Therefore, it follows that one effect of repeated visits to the same site would be to cause the curve of Hiker A to shift closer to this ideal (Fig. 4), assuming that familiarity with this site does not reduce its attractiveness.

The effects of underestimating distance can also be illustrated graphically (Fig. 5). In this case, the motivation level increases more rapidly than it should. Inevitably, however, people come to realize that they still have farther to go than they had thought, and the strength of motivation will decline. This decline represents disappointment and frustration ("Oh, you mean we're only here? I thought we were nearly there!"). The greater this decline is, the more disappointment there will be, and the more it will detract from the overall quality of the experience. This type of situation might occur when people are hiking on mountains with "false" summits.

Fortunately, management can reduce the impact of these two outcomes by providing stimuli that show the visitor where he is in relation to a site. One good example of this type of management is found on interstate highways where signs giving the distance to the next major city appear at frequent intervals. Most of us probably have had the experience of becoming increasingly excited each time we see a sign that tells us that our destination is nearer. In addition, these signs also prevent us from underestimating the remaining distance.

The same principle can be applied in forested recreation areas. The simplest way would be to provide signs that actually show the vis-

Figure 4.—Effect of repeated visits to the same goal by the same person.



itor how much distance remains. However, any stimulus that reveals that information will do as well, and other stimuli may be more appropriate for use in natural areas. To use the waterfall example, suppose that Hiker A had a map showing another trail crossing the waterfall trail about halfway out. Then, when A arrived at this spot, he would know he had traveled half the distance. This knowledge would increase his motivational level and also would help him to make more accurate estimates of distance during the remainder of the journey. This effect is illustrated in Figure 6, where two stimuli, one at 14 minutes away, the other 6 minutes away, are applied to one hiker walking out to the waterfall. The shaded area indicates the extent to which these stimuli have improved the quality of his experience.

It also seems possible that providing these stimuli may affect the rate of learning that occurs, thereby reducing the amount of time required to approach the ideal curve. In other words, fewer repeated visits should be needed for the hiker to approach the ideal curve.

Finally, the question arises: how many of these stimuli should be provided? The actual number will, of course, vary with the length of the distance to be covered. Perhaps we can borrow some concepts from economics to answer the question. For any given distance, then, there will be a point of diminishing marginal return where each additional stimulus contributes less to the quality of the experience than the previous one. Beyond this, there should be a point where the "marginal cost" of an additional stimulus will be equal to its

Figure 5.—Effects of understanding the remaining distance to a goal.

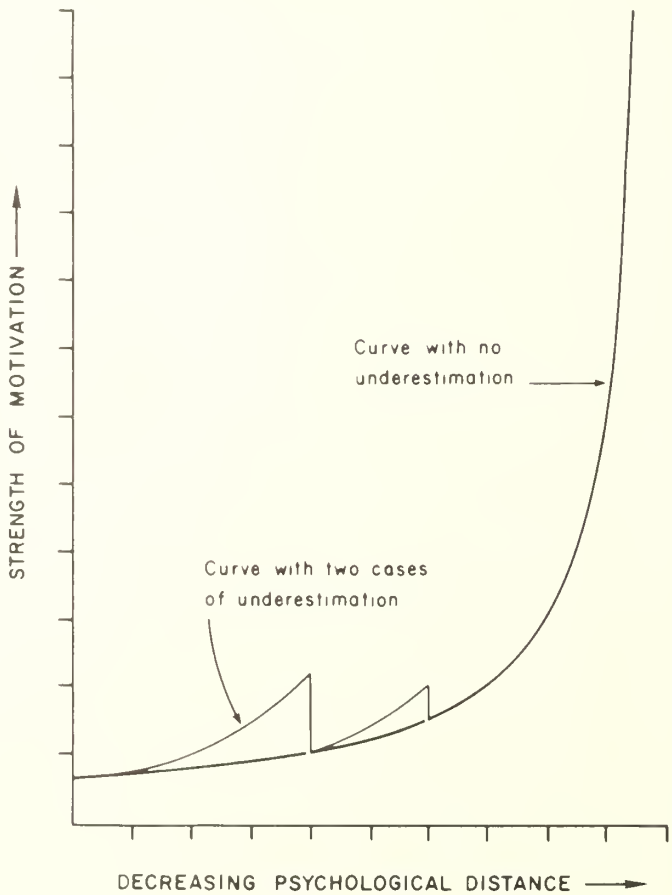
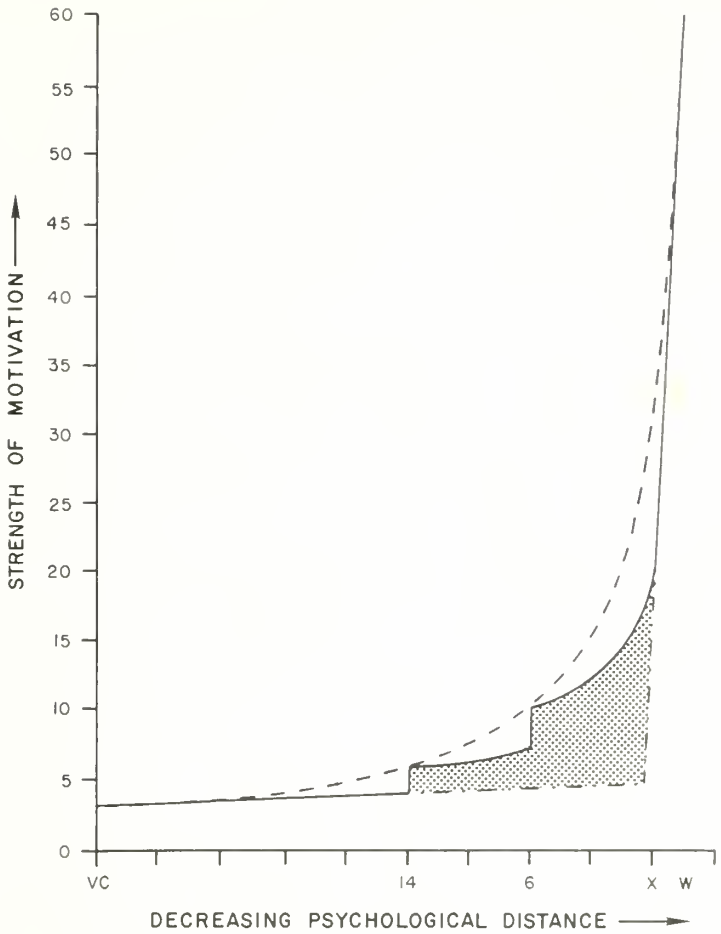

STRENGTH OF MOTIVATION
Curve with no underestimation
Curve with two cases of underestimation
DECREASING PSYCHOLOGICAL DISTANCE

Figure 6.—Effects of two stimuli on the quality of the recreation experience.



"marginal benefit." This, naturally, would be the optimal number of stimuli to provide. An excessive number of stimuli may detract from the quality of the experience by reducing the attractiveness of the goal.

These examples are greatly oversimplified for illustrative purposes, and are based upon assumptions that may be unrealistic (for example, equal and unchanging attractiveness levels). In reality, people probably fluctuate around the ideal curve, switching back and forth between overestimating and underestimating distance. The key point, however, is that managers can reduce the impact of these fluctuations by providing stimuli that serve as landmarks.

USING THE THEORY TO REGULATE USE

Recreational carrying capacity is a broad subject that has attracted considerable attention (Frissell and Stankey 1972). In fact, the large number of proposed definitions is indicative of the breadth of the concept. According to Brown et al. (1976), carrying capacity can be conceived as "that configuration of use (amount, distribution, type, etc.) which is consistent with the long-term production of a specified recreational experience or set of such experiences." Thus, the amount and distribution of use are an important factors in identify-

ing whether current use levels are within the carrying capacity of an area.

In our opinion, this theory offers a useful approach for regulating use after management has decided on a particular use level. Suppose the decision had been made to try to increase the use of a particular site or facility. Management might then try to make the site more attractive to visitors and easier to get to; that is, increase the attractiveness and decrease the psychological distance. There is some indication that by modifying the attributes of a site, the time people spend there can be changed. In fact, the amount of time people spend at a site may well be a good indicator of its attractiveness (Buhyoff 1975).

Another common difficulty in forest recreation areas today is reducing the level of use in overcrowded facilities. In this case, management can attempt to decrease motivation by decreasing the attractiveness or increasing the psychological distance, or both. Returning to the Rhododendron Gap example, suppose ecological degradation was beginning. What could be a simpler solution than to change the name to something less attractive? Many people who had learned to appreciate attributes of this site other than its name would probably continue to visit it, but we would expect the number of new visitors to decline and total use to decline over time.

The theory can also be used to help attain a desired use distribution within an area by providing an insight into how visitors make decisions about goals. Most large natural areas offer the visitor more than one potential goal. To a visitor at the gate, each of these goals has some attractiveness level associated with it. Although it is oversimplifying, we can say that visitors will select the goal that they are most motivated to attain (the highest M value). Therefore, when an area offers several goals, it may be possible to manipulate the motivations created by each in order to distribute the amount of use in a more desirable manner.

Suppose that an area offers a number of potential goals. By increasing the attractiveness of some goals, while decreasing the attractiveness of others, it may be possible to achieve the desired use distribution. In fact, it may be desirable to think in terms of attractiveness regions—groups of goals whose attractiveness can be manipulated relative to one another, thereby regulating motivational level. In the case of the Boundary Waters Canoe Area, providing the information on use patterns apparently shifted the relative attractiveness of different trips. Or creating a new access point will affect use distribution by changing psychological distances. When the motivations to visit goals throughout an area are nearly equal, an even distribution of visitors would be expected.

Many of the above management techniques for manipulating motivation and attractiveness are currently in use and have been discussed in the literature. For instance, Brown and Hunt (1969) pointed out the role that informational signs can play in effecting changes in visitor distribution and use, while Wagar (1974) suggested that such changes can also be accomplished by interpretation.

Another possibility for regulating use might be to remove the motivation to visit a particular goal altogether by eliminating references to it on maps and other publications. If people have no knowledge that a goal exists, then there can be no motivation to visit it, and they will respond only to the remaining motivations. This might greatly reduce the amount of use that a site receives. This approach is currently being used in Shenandoah National Park, where all designated backcountry campsites are being eliminated in the hope that campers will distribute themselves more evenly, and in Acadia National Park, where overuse has threatened the Anemone Cave.

SUMMARY

A primary objective of all resource management is the production of sustained benefits for people. In recreation resource management, one facet of this objective is the production of high-quality recreation experiences. We believe that field theory offers insights which can help to accomplish this. Of course, Lewin's (1951) theoretical work was not specifically designed to be applied to the topics discussed here, nor have we used all the constructs from field theory. As a result, the simplified version pre-

sented here glosses over many pertinent factors governing recreation behavior.

Perhaps even more important, much of our argument rests on the assumption that motivation and emotion are related. Readers should be cautioned that this is an assumption in the classic sense—though it seems to fit well without intuitive experience, there is little evidence to support it. Nevertheless, we feel that field theory offers a good base upon which to build systematically. Initial evidence suggests that variables within this model can be quantified successfully and that the mathematical relations suggested can be tested (Hoar 1977). It is hoped that future work can clarify relations among motivation, attractiveness, psychological distance, and other factors that may affect on-site behavior and the quality of recreation experiences.

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Abstract

Results of two independent studies were analyzed to determine whether residual stocking after thinning had any effect on change in stem form of upland oak. One study is based on 15 years' change in Girard Form Class after thinning of an 80-year-old white oak stand in eastern Kentucky. The other, 12-year changes in Girard Form Class and breast-height form factor based on Barr and Stroud Dendrometer measurements in 35-year-old thinned upland oak stands in Ohio, Kentucky, and Missouri. Sample trees in both studies were in the dominant and codominant crown classes. Neither study showed any significant differences in stem form changes that could be related to residual stocking. The change in stem form, however, was significantly correlated with the initial form for all stocking levels. Trees with the best form were more likely to deteriorate in form while the poorly formed trees were most likely to improve, regardless of the residual stocking level.

INTRODUCTION

FOR MANY YEARS foresters have been concerned that heavy thinning may cause the stem form of residual trees to deteriorate, and consequently volume equations or tables that are usually based on uncut stands may overestimate volume growth in managed stands. If stem form changes were severe, a modification of the volume table or equation would be needed to predict stem volume and volume growth accurately.

In a comprehensive review of studies on stem form development, Larson (1963) points out that one of the most controversial aspects of the problem is the degree to which thinning alters stem form. Several authors have found that releasing a well-formed stand-grown tree results in a free-growing tree with more taper (Larson 1963). Other authors have reported that thinning causes the residual trees to grow toward a common form class (Meyer 1931, Behre 1932). Well-formed trees are reported to deteriorate in form after thinning, while the poorer formed trees improve in form.

The objective of our studies was to determine whether the residual stocking level after thinning had any effect on stem form change in upland oaks.

THE STUDIES

The plots used in both studies were part of a larger regional study of stand density designed to develop growth and yield relations for thinned upland oak stands. All plots were originally well-stocked even-aged stands with no evidence of recent disturbances such as cutting, fire, or grazing. The site quality is typical for much of the upland region, ranging between site index 60 and 75 for black oak.

The first study was established in 80-year-old white oak stands on the Baldrock Experimental Forest in southeastern Kentucky. Sixteen 1-acre plots were thinned initially in 1959 so that the residual stand ranged from about 24 to 77 percent stocking, based on Gingrich's (1967) tree-area-ratio equation. Girard Form Class was determined for a sample of 368 dominant or codominant white oak *(Quercus alba* L.) in 1959 and 1974 (Table 1). Stem diameters at 4.5 ft and 17.3 ft were measured outside bark with a diameter tape. The exact point of measurement was permanently marked so that later measurements would be taken at the same place. A ladder was used so that the measurements of upper stem diameter and double bark thickness (made with a Swedish bark gauge) could be accurately read. Some

Table 1.—Summary statistics for two stem form studies of upland oaks

Stocking level (percent)	Number of trees	Average dbh, outside bark (inches)		Average height (feet)		Average age (years)		Average site index
		BALDROCK STUDY						
		1959	*1974*	*1959*	*1974*	*1959*	*1974*	
<50	177	10.4	13.1	74.0	82.3	80	95	63
50-75	142	10.5	12.5	75.6	87.2	72	87	64
75+ (control)	49	10.5	12.6	76.7	88.4	80	95	66
All trees	368	10.4	12.8	75.0	85.0	77	92	64
		BARR AND STROUD STUDY						
		1964	*1976*	*1964*	*1976*	*1964*	*1976*	
<50	33	6.9	9.6	52.1	63.0	35	47	69
50-75	45	6.9	8.8	49.9	61.3	34	46	71
75+ (control)	34	7.0	8.7	53.2	64.6	37	49	69
All trees	112	6.9	9.0	51.5	62.8	35	47	70

study plots were thinned again in 1970, but these were all very light cuts. This first study will be referred to as the Baldrock study.

The second study used several upland oak species with an average age of about 35 years. The plots were located in three widely separated geographical areas: southeastern Ohio, east-central Kentucky, and south-central Missouri. We refer to this as the Barr and Stroud study simply because all measurements of upper stem diameter were made with the Barr and Stroud Dendrometer in 1964 and 1976. Trees were sampled on 34 half-acre plots that had been thinned in 1961 or 1962 to various stocking levels so that the residual stand ranged between 27 and 93 percent stocking. Some of the higher stocked plots were never thinned, and some plots received a second light thinning between 1968 and 1971.

The results are based on 112 dominant or codominant trees: 41 white oak, 51 black oak (*Q. velutina* Lam.), 14 scarlet oak (*Q. coccinea* Muenchh.), and 6 chestnut oak (*Q. prinus* L.) (Table 1). Dendrometer readings were taken at 6 to 11 points along the bole of each tree, and with the appropriate bark-thickness factor, an inside bark diameter was assigned to each measurement point. Then, by a linear interpolation procedure, diameters were computed for the specific points needed to calculate the Girard Form Class and the breast-height form factor for each stem.

For statistical analyses, data for each study were separated into three stocking levels based on the average percent stocking of the plots over the measurement interval: less than 50 percent, 50 to 75 percent, and greater than 75 percent. Data from plots that averaged greater than 75 percent stocking essentially represent a control treatment (no thinning to very light thinning). Table 1 shows the number of sample trees and the initial and final average dbh and total height by stocking levels for both studies. The initial average dbh for the three stocking levels was about 10.4 inches for the older trees in the Baldrock study and about 6.9 inches for the younger trees in the Barr and Stroud study.

MEASURE OF STEM FORM

In its narrowest sense, stem form refers to the shape of the stem. It is defined by the Society of American Foresters (Ford-Robertson 1971) to mean the degree and mode of taper in the stem, most often expressed by a numerical value such as form quotient or form factor. In this paper we use the *Girard Form Class* and the *breast-height form factor* to express stem form. Girard Form Class is the percentage ratio of diameter inside bark at 17.3 ft (5.27 m) to dbh outside bark. The breast-height form factor is defined as the inside bark volume of the stem from dbh to total height, divided by the volume of a cylinder whose base is dbh inside bark, and length is the distance from dbh to total height.

ANALYSIS AND RESULTS

The average changes in Girard Form Class and breast-height form factor are shown in Table 2. There was an increase in Girard Form Class for all stocking levels in both studies. Form factor, however, decreased on the two lower stocking levels. To help explain this apparent contradiction, we used the data collected on upper stem diameter from the Barr and Stroud study to develop Figures 1a-1c. These figures show the percent of height above dbh plotted over the ratio of diameter inside bark to dbh inside bark for each of the three stocking categories. These figures reveal that *on the average* growth was concentrated on the basal part of the stem. The concentration of growth continued up the stem at least as far as 17.3 ft (5.27 m). Stem growth at 17.3 ft increased relative to dbh inside bark, hence the increase in Girard Form Class. Figures 1a-1c also reveal that upper stem growth was reduced relative to dbh inside bark, hence a reduction in form factor. These figures may explain some of the differences reported in the

Table 2.—Statistics for Girard Form Class and breast-height form factor for two studies of upland oaks, by stocking level

Stocking level (percent)	Number of trees	Average initial form	Average change in form	Correlation between form change and initial form
BALDROCK STUDY—Girard Form Class				
<50	177	77.14	+1.22**	−0.178*
50-75	142	75.91	+1.50**	−0.306**
75+ (control)	49	77.40	+0.67	−0.365**
All trees	368	76.70	+1.25**	−0.253**
BARR AND STROUD STUDY—Girard Form Class				
<50	33	73.69	+1.10	−0.603**
50-75	45	71.20	+3.55**	−0.605**
75+ (control)	34	72.42	+3.00**	−0.643**
All trees	112	72.30	+2.66**	−0.609**
BARR AND STROUD STUDY—Breast-Height Form Factor				
<50	33	0.374	−0.015*	−0.391*
50-75	45	0.368	−0.005	−0.437**
75+ (control)	34	0.373	+0.004	−0.430*
All trees	112	0.371	−0.005	−0.408**

**Significant at 0.01 level.
*Significant at 0.05 level.

igure 1a.—Diameter inside bark atios, stocking less than 50 percent. Barr and Stroud study. ased on 33 stems.

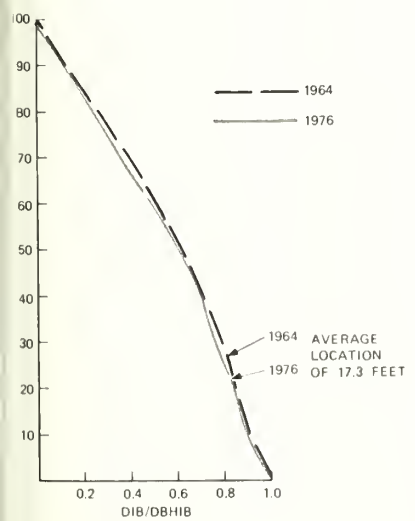


Figure 1b.—Diameter inside bark ratios, stocking 50 to 75 percent. Barr and Stroud study. Based on 45 stems.

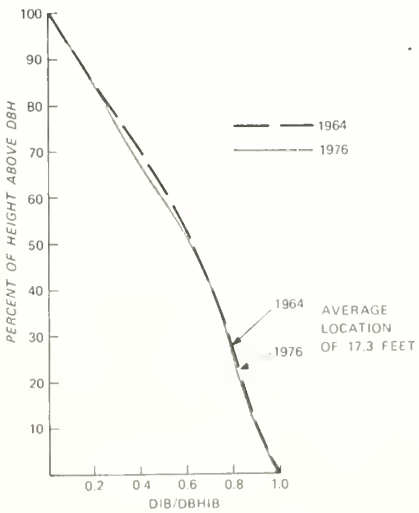
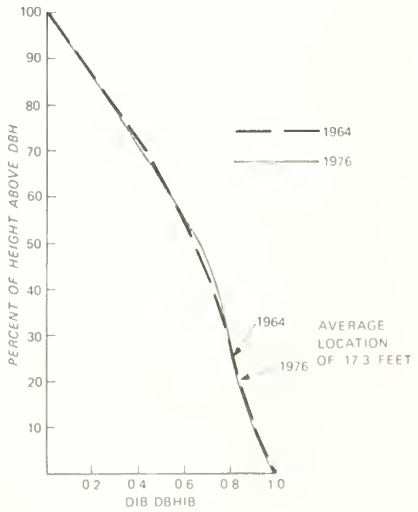


Figure 1c.—Diameter inside bark ratios, stocking greater than 75 percent. Barr and Stroud study. Based on 34 stems.



literature on the effect of stocking on stem form. Analyses on the same set of data using different expressions of stem form can result in contradictory conclusions. Girard Form Class is an excellent measure of form for the butt log, which is often of primary interest, but form factor appears to be a better expression for the entire main stem.

Correlation analyses and scatter plots revealed that variations in site, age, dbh, and species within a study did not have much influence on stem form changes. Changes in stem form, however, were significantly correlated with initial stem form (Table 2). Trees with a high initial form class or form factor deteriorated in form, or at least did not improve as much as trees with a low initial form. Regressions of change in stem form on initial stem form were fitted by least squares for all trees in each stocking level and plotted over the range of the data to graphically illustrate this relationship (Figs. 2a-2c). This result is consistent with the findings of Meyer (1931) and Behre (1932).

Figure 2b.—Relationship between change ir Girard Form Class and initial Girard Form Class by stocking levels. Barr and Stroud study.

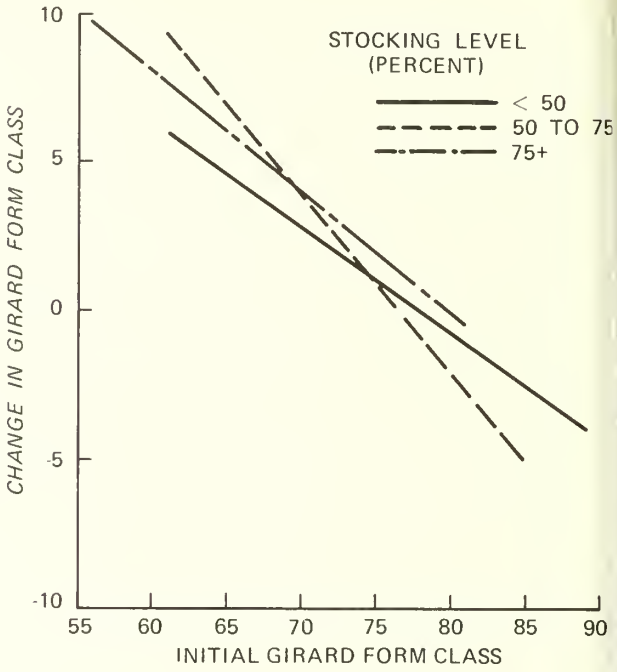


Figure 2a.—Relationship between change in Girard Form Class and initial Girard Form Class, by stocking levels. Baldrock study.

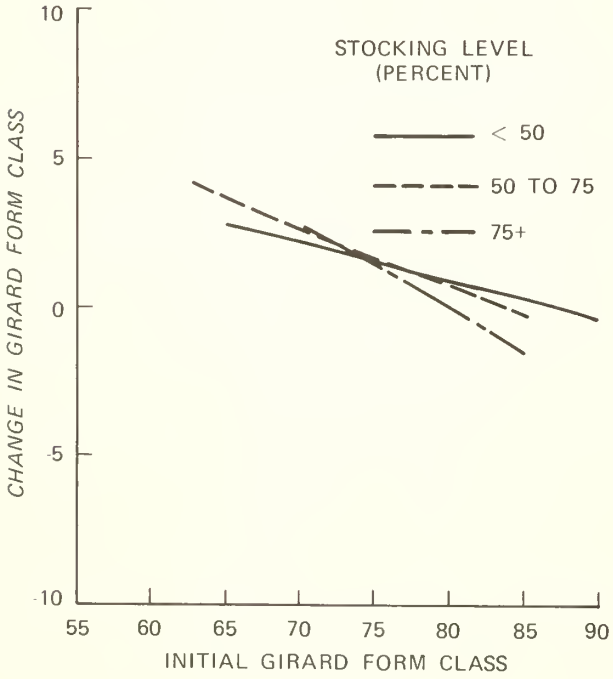
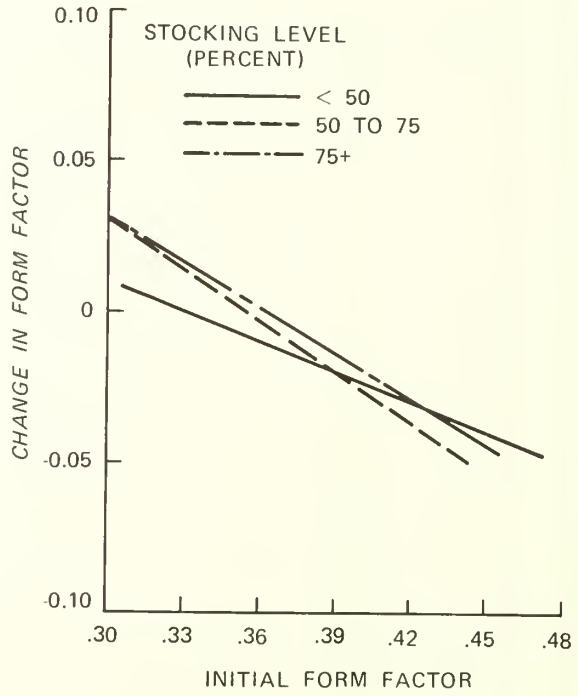


Figure 2c.—Relationship between change in breast-height form factor and initial form factor, by stocking levels. Barr and Stroud study.



The change in the average stem form for a stand, therefore, is dependent on the form of the residual trees after thinning. If only those trees with lower than average form are left after thinning, one would expect an improvement in stem form. If only those trees with better than average form remain after thinning, one would expect a deterioration in stem form, or at least not as marked an improvement (see Fig. 2a). It is important to note that the relationship between stem form changes and initial stem form holds for *all* stocking levels, even the 75+ percent level. Therefore, the relationship cannot be attributed to thinning alone.

The relationship between stem form changes and initial form illustrated in Figures 2a-2c was consistently the same within individual stocking plots. It was also consistent between plots when the range in initial form was not the same for all plots. Since statistical tests revealed no significant differences between the slopes of the within-plot regression lines for a given stocking level, we used the individual trees within a stocking level as observations to construct the regression lines in Figures 2a-2c.

Statistical tests to determine the equality of the regression lines in Figures 2a-2c were performed for each study (Table 3). As expected, initial form accounted for a significant part of the variation in the change in form. The hypothesis of equal slopes between stocking levels could not be rejected in any of the three analyses. The overall F test for differences in the intercepts was not significant at the 0.05 level for any of the three analyses. We conclude that the regression lines are the same for all three stocking levels. Thinning did not have a statistically significant effect on stem form changes.

EFFECT OF FORM ON VOLUME ESTIMATION

The effect of stem form on volume estimation can be considerable. It is well known that the difference between one Girard Form Class and another amounts to approximately 3 percent in terms of merchantable volume (Avery 1967). When Girard Form Class volume tables

Table 3.—Analysis of covariance tables for stem form changes in two studies of upland oaks

Source of variance	Degrees of freedom	Mean square	F value
BALDROCK STUDY—Girard Form Class			
Difference for testing common intercepts	2	6.3628	0.9391^{NS}
Initial form	1	156.1538	23.0474**
Error	364	6.7753	
Difference for testing common slopes	2	5.9625	0.8795^{NS}
Error	362	6.7798	
BARR AND STROUD STUDY—Girard Form Class			
Difference for testing common intercepts	2	20.3763	2.1069^{NS}
Initial form	1	560.6309	57.9697**
Error	108	9.6711	
Difference for testing common slopes	2	21.5906	2.2856^{NS}
Error	106	9.4462	
BARR AND STROUD STUDY—Breast-Height Form Factor			
Difference for testing common intercepts	2	0.0031	2.4756^{NS}
Initial form	1	0.2800	22.5652**
Error	108	0.0012	
Difference for testing common slopes	2	0.0006	0.4958^{NS}
Error	106	0.0013	

NS—Not significant at the 0.05 level.
**Significant at the 0.01 level.

are used, the form class is determined and the appropriate volume table is then selected. This procedure acts as a check against using the wrong volume table if stem form changes. Girard Form Class tables, however, are seldom used for upland oaks.

The effect of stem form on volumes estimated from empirically constructed volume tables is less distinct. Actual cubic foot volumes, inside bark, were calculated from the dendrometer readings in the Barr and Stroud study for the 112 trees. Tabular cubic foot volumes, inside bark, were read from Schnur's (1937) volume tables. Ratios of actual volumes divided by tabular volumes were regressed on form factor and plotted in Figure 3. An increase of 0.05 in form factor resulted in a 7 percent increase in the actual to tabular volume in 1964, and a 12 percent increase in the actual to tabular volume in 1976. The difference between the rates of increase can be attributed to the fact that the form factor is not constant over all diameter and height categories in Schnur's volume tables. The effect of form on volume estimation is indeed striking.

We also investigated the capability of Schnur's volume tables to consistently estimate the actual cubic foot volumes of trees before thinning (in this case, immediately after thinning) and 14 to 15 years after thinning. The character of the sample trees may not be representative of the volume table under consideration, but, as Meyer (1931) points out, it is the relative change, or progressive differences in the ratio of actual to tabular volume that is of primary interest. The mean ratios of actual to tabular volumes in 1964 and 1976 are listed by stocking levels in Table 4 for the Barr and Stroud study. The character of the sample trees in this case was representative of Schnur's volume tables because the mean of ratios was near the value one. The largest change in the mean ratios was −0.03. The change in ratios for the 75+ percent stocking level was only −0.01. None of the changes was significant at the 0.05 level. We conclude that a modification of Schnur's volume tables is not necessary when they are used for estimating cubic volumes of trees in thinned stands.

Even if the change in average form factor

Figure 3.—Effect of stem form on volume estimation. Barr and Stroud study. Based on 112 stems, and Schnur's volume tables.

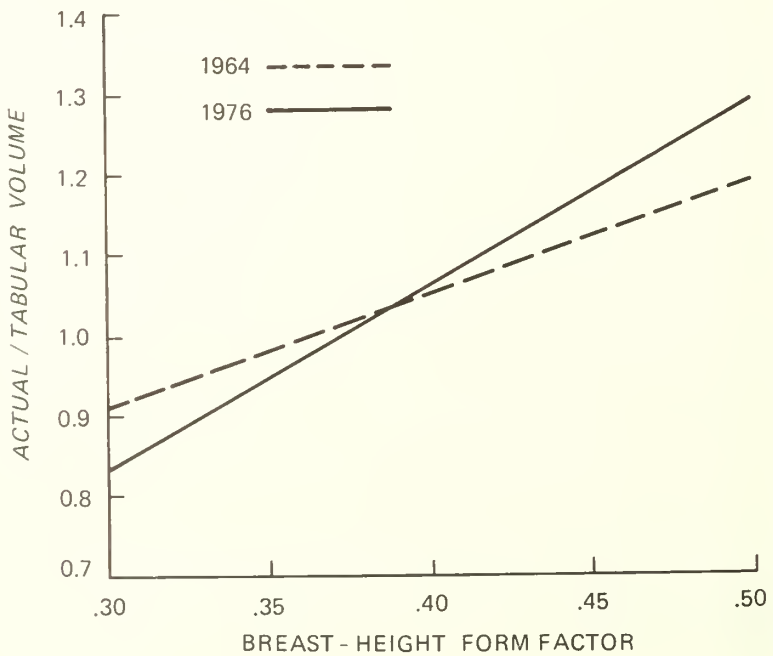


Table 4.—Mean ratios of actual to tabular volumes for Barr and Stroud study of upland oaks, by stocking level

Stocking level (percent)	1964	1976	Change
<50	1.02	0.99	−0.03[NS]
50-75	0.99	0.96	−0.03[NS]
75+	1.02	1.01	−0.01[NS]
All trees	1.01	0.98	−0.03[NS]

NS—Not significant at the 0.05 level.

after thinning is highly significant, like the −0.015 average change for the lowest stocking level in the Barr and Stroud study, the volume table under consideration may still be applicable. Figure 3 reveals the reason. The ratio of actual to tabular volume for a tree may increase over time even if its form factor decreases, and may decrease over time even if its form factor increases.

DISCUSSION

The results of these studies indicate that stocking levels after thinning do not have a significant effect on the stem form of upland oaks. The 12- and 15-year intervals between measurements seem sufficient to detect form changes. Form changes caused by age may mask the effect of stocking if the measurement period is much longer.

Larson (1963) points out that measurements restricted to the dominant and codominant trees may lead one to the conclusion that thinning has no effect on stem form. Other studies have reported that the failure of dominant trees to respond to thinning or release is evidently due to their strongly built, tapering stems. It can be argued, however, that the dominant and codominant trees are the trees of interest. Stem form changes in these larger trees affect volume estimates to a much greater degree than those for intermediate and suppressed trees.

There was a tendency for trees with below average form to become more "cylindrical" after thinning, and trees with above average form to "deteriorate" in form, or at least not improve as much as trees with below average form. This was the case even on the 75+ percent stocked plots. The relationship between form change and initial form should be recognized when analyzing stem form changes. Failure to do so could lead to erroneous conclusions.

We have also shown that trees that exhibit an increase in Girard Form Class may in fact show a decrease in form factor. Caution should be used when drawing conclusions about form changes when only one measure of stem form is available.

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Abstract

An oak soil-site productivity equation was developed for the well-drained, upland soils in the northwestern portion of West Virginia adjacent to the Ohio River. The equation uses five easily measured soil and topographic variables and average precipitation to predict site index. It accounts for 69 percent of the variation in oak site index and has a standard error of 4.3 feet at the mean site index of 67.6 feet. The equation was tested with data from 61 independent plots, and the results showed a correlation of 0.83 between predicted and observed site indexes.

INTRODUCTION

NUMEROUS STUDIES have related forest productivity in a given area to various soil and topographic features of the landscape. Six such studies have been completed for oaks in parts of West Virginia, western Maryand, Ohio, and Pennsylvania (Gaiser 1951, Trimble and Weitzman 1956, Yawney 1964, Carmean 1965, Yawney and Trimble 1968, Bowersox and Ward 1972). In addition, many other site studies have confirmed the importance of aspect, position on slope, and slope steepness as well as soil depth, texture, and drainage for predicting site quality of a large number of species (Carmean 1970, 1973, 1975).

In northwestern West Virginia, oaks are the dominant hardwoods, but a large portion of these stands are unsuitable for direct site index determinations because of early suppression, previous partial cuttings, and detrimental land use such as grazing, or fire and erosion. The purpose of this study was to derive an equation that could be used by foresters and land managers to predict oak site quality from easily measured soil and topographic variables where suitable stands for direct site index determinations are not present.

STUDY AREA

This study was conducted in northwestern West Virginia (Fig. 1; see Appendix for all figures), an area that contains about 1.3 million acres of upland oak forests (Ferguson 1964). The region is characterized by similar recurring topographic patterns, several major soil series and their intergrades, and an annual precipitation from 40 to 48 inches. Elevation ranges from about 600 feet in the valley bottoms to about 1,400 feet on the ridges and upper flats. The terrain varies from gently rolling topography on upland flats to the steep side walls of narrow valleys that exceed 50 percent slope.

The major forest types of the upland portion of the region are dominated by five species of oak: red oak (*Quercus rubra* L.), black oak (*Q. velutina* Lam.), white oak (*Q. alba* L.), scarlet oak (*Q. coccinea* Muenchh.), and chestnut oak (*Q. prinus* L.). Red oak is most abundant on the better sites, but is frequently found throughout the range of sites. Black and scarlet oak are found primarily as scattered individuals. White oak, often found in nearly pure stands—though also mixed with the other oaks—is most abundant on dry southern exposures. Chestnut oak usually dominates the ridge tops and the poorest sites. In the best stands, which are located on deep, moist soils in coves and on concave middle and lower slopes of northern exposures, oaks are generally found only as scattered individuals mixed with yellow-poplar (*Liriodendron tulipifera* L.).

The majority of the upland soils within the region are residual, having formed in parent material weathered from the Dunkard geologic formation. The Dunkard formation consists of alternating strata of acid gray sandstone and siltstone, and red clay shale, which gives rise to greatly contrasting soils where these different strata surface. Much of the area has been affected by erosion and colluvial deposition, and has developed bench-slope topography with an intricate soil complex. Three major soil series—Muskingum, Gilpin, and Upshur—and their intergrades were recognized in this study.

The major land use for the entire area was once agriculture, and the degree to which existing forest land was affected by sheep and cattle grazing is not known. Much of the original farmland has since reverted to timber.

Fires have been numerous and widespread, and erosion on much of the area was prevalent in the past.

STUDY METHODS

We established 91 plots in fully-stocked, even-aged oak stands that showed no evidence of past cutting, and which appeared free of fire and grazing in recent years. Only stands ranging in age from 40 to 70 years and on well-drained sites with uniform soils and surface configuration were sampled.

On each plot, a minimum of 10 dominant and codominant oaks were measured for total height and age at breast height, and then combined for an average oak site index.[1] The trees measured were those growing nearest to the plot center and that showed no evidence of previous top breakage or suppression. Height measurements were taken during the leafless period to ensure accuracy. Three years were added to the age to arrive at total age. The plots ranged in size from about 0.1 to 0.4 acre to include the prescribed number of trees.

Three evenly spaced soil pits were dug on each plot to bedrock or 6 feet, whichever was shallowest. The soil series or intergrade was identified. Thickness, pH, Munsell color, texture (feel-at-the-pit method), and stone content of each horizon were determined. Values from the three pits were averaged to represent the plot. Ten supplementary A_1 thickness determinations were made on each plot and averaged with the A_1 data from the soil pits.

Topographic information on each site included: aspect, slope steepness, distance to ridge or upper flat, total slope length, azimuth and angle to highest surrounding land, lateral slope shape, and land form. Values for precipitation were obtained from published climatic tables (Grafton and Dickerson 1969). Elevation, latitude, and longitude were determined from U.S. Geological Survey (USGS) topographic maps. The solar radiation reaching each plot during the growing season and the radiation index based on aspect, slope steepness, and latitude were calculated from published tables (Frank and Lee 1966). Stand age was determined from increment cores and expressed as its reciprocal. The site index was determined from existing height/age curves (Schnur 1937).

Forty-six independent variables and transformations for predicting stand height, site index, and log site index were evaluated by multiple regression with backward elimination procedures (Draper and Smith 1966). The relationship between site index and aspect (azimuth) was computed by entering the sine and cosine of azimuth × slope steepness and slope steepness as three separate independent variables according to the procedure described by Stage (1976).

The final prediction equation was tested for field application by comparing the predicted values to the observed site indexes derived from an independent study on 61 soil-site plots.[2] These plots were located within the study region and included the same soil series as well as six others.

RESULTS

Data collected in this study show that the site index for oak within the region ranges from a low of 47 to a high of 85 (Table 1; see Appendix for all tables). However, both poorer and more productive sites may exist that were not included in our sampling. The mean site index among soils varied only slightly and differences among soils were not significant ($P \leq 0.05$), which indicates that other factors are important for tree growth.

The equation

Because there were no overall differences in site quality among the different soils, data were combined to derive a prediction equation applicable to all well-drained residual soils of the uplands. Of the 46 independent variables that were originally tested (see Appendix), 6 were significantly related to site index ($P \leq$

[1]Combining species that have known differences in site index represents an unaccountable source of variation in the derived prediction equation. However, from a practical standpoint, mixed stands of oak are far more common than pure stands, and "oak species" allows for the use of existing yield tables that are applicable to the region.

[2]These data were provided by John L. Gorman, Woodland Conservationist, Soil Conservation Service, Morgantown, W. Va.

0.05). The same six were also strongly correlated with stand height and the log of site index, but multiple coefficients of determination (R^2) were slightly less than with site index. The regression equation selected is:[3]

$$Y = -b_o + 2.897\ (X_1) + [7.026\ (X_2) \times \text{Cos}\ (X_3)] - 9.216\ (X_2) + 2.859\ (X_4) + 0.081\ (X_5)$$

where:

Y = site index (height at age 50, in feet)
b_o = slope shape—a discrete variable expressed numerically as follows:

convex slope = −58.761
linear slope = −55.988
concave slope = −52.377

X_1 = thickness of A_1 soil horizon (inches)
X_2 = slope gradient (percent slope/100)
X_3 = aspect (azimuth of the plot minus 81°)
X_4 = precipitation (inches to a maximum of 44)
X_5 = position on slope (percentage of total slope length)

With the exception of slope gradient, prediction variables are significant at the 0.05 level. The strongest predictors of site index are thickness of the A_1 soil horizon and aspect. When individual prediction variables were regressed separately with site index, the quantities of explained variation were:

Variable	R^2 (*percent*)
A_1 thickness (X_1)	44
Aspect (X_2) and slope gradient (X_3)	20
Precipitation (X_4)	9
Position on slope (X_5)	3

Correlations among independent variables were significant ($P \leq 0.05$) only between the thickness of the A_1 soil horizon and the aspect ($r = 0.26$). The remaining independent variable correlations were less than 0.20 and most were less than 0.10, which suggests that the prediction equation is relatively free of intercorrelation problems.

[3]The equation also includes the reciprocal of stand age as a variable to correct site index values for differences between the height/age curves used to determine site index and the actual height/age patterns of our sample. However, when the equation is used to predict site index at age 50, this variable becomes a constant, and has therefore been incorporated into the b_o's to simplify the equation.

Equation verification

The equation was tested against independent data from 61 soil-site plots. The correlation coefficient between predicted and observed site index was 0.83, significant beyond the 0.01 level. The regression equation accounted for 69 percent of the variation in predicted site index and had a standard error of estimate of 4.3 feet, essentially identical to the fit of the original prediction equation (Fig. 2). Seventy-two percent of the predicted values were within five points of the observed site index. Of the 61 predictions, 69 percent overestimated and 31 percent underestimated the measured site index. Although there is a strong correlation between predicted and actual site index, the equation tends to overpredict by approximately two site index points with this data set. Nevertheless, we feel that its accuracy is sufficient for field use since most deviations are within the error of practical determination.

Independent variables

Each soil and topographic variable in the equation has a biological implication—directly or indirectly they describe the moisture regime, the soil depth, or the fertility of the site. Each variable, as used in the equation, is approximately linear over the range of conditions sampled.

A_1 thickness (X_1). Thickness of the A_1 soil horizon varies with aspect (correlation coefficient = 0.26); the horizon is of minimal thickness on dry west and southwestern exposures, intermediate on southeastern and northwestern exposures, and maximum on east and northeastern-facing slopes. Depth of the A_1 also is influenced (but not statistically with these data) by species composition of the existing stand—whether the slope is convex, concave, or linear—and by the position of the site on the slope. On southwestern and west-facing slopes, increasing slope gradient is accompanied by decreasing A_1 thickness, but slope gradient has only a minor influence on the A_1 horizon on favorable aspects. Site

quality increases by about three site index points for each additional inch of A_1 soil horizon.

Generally, the A_1 thickness is least on steep, convex, southwestern exposures on the upper 25 percent of the slope in stands dominated by oak. It is maximum on concave, northeastern exposures on the lower 25 percent of slopes where yellow-poplar and basswood (*Tilia americana* L.) are major stand components. The A_1 thickness is an indicator of soil fertility and particularly of the site's capacity to supply nitrogen.

Slope gradient (X_3). Slope gradient is used in the equation to modify the amplitude of the cosine function of azimuth. In effect, it provides for the negligible influence of aspect on flat or gently sloping terrain and on favorable eastern exposures, but allows the equation to describe increasingly adverse conditions with increasing slope gradient on unfavorable western aspects (Fig. 3). On eastern exposures, site index decreases only one point with a 40 percent increase in slope steepness, but on western exposures it decreases two site index points for each 10 percent slope increase.

Aspect (X_4). Aspect is expressed in the equation as the cosine of azimuth with a phase shift angle of 81° from north which is modified by slope gradient. The cosine transformation imposes approximate linearity between site index and azimuth. The phase shift angle of 81° places the best sites at N81°E and the least productive at S81°W, a shift of 23° to 35° further east than the normal 45° to 58° shift used for adjustment in most other soil-site investigations.

Site quality varies only slightly within ± 45° of N81°E and S81°W, even on slopes with gradients exceeding 50 percent; on slopes with grades less than 10 to 15 percent, the influence of aspect is negligible (Fig. 3). For the average 35 percent slope within the study region, site quality varies about 5 site index points from the most favorable to the least favorable aspects. However, this change in aspect is normally accompanied by a large change in thickness of the A_1 soil horizon (deeper A_1's on northern and east-facing slopes) expanding the site index spread to about 13 points.

Precipitation (X_7). Small increases in precipitation during the summer when forests are subject to intermittent soil moisture stress are important for increasing site productivity. Within the study region, rainfall generally increases from west to east and from south to north. Site index increases directly with increasing precipitation from the 40- to the 44-inch level at a rate of three site index points per additional inch of precipitation. There was no relationship between site index and precipitation above 44 inches.

Position on slope (X_5). Upper slope positions usually have the driest, stoniest, and shallowest soils with a minimal A_1 soil horizon. In contrast, lower slopes have deeper soils that are frequently more moist, sometimes stone-free, and with maximum A_1 accumulation. Site index increases by about six points from upper to lower slopes, although frequently there are larger differences if the A_1 thickness increases with increasing distance from the ridge. Although not considered in the equation, a rapid decline in site quality often occurs on near-crest positions due to shallow soils.

Slope shape (b_6). Slope shape is a discrete variable that refers to the lateral topographic configuration of the slope. Convex slopes are generally drier and have shallower and more stony soils than concave slopes; linear slopes lie in an intermediate position. In general, site quality is lowest on convex upper slopes and highest on lower slopes with concave relief. Site index varies by three points between convex and linear and between linear and concave slopes. Concave land forms are often associated with greater A_1 depths than either linear or convex topography.

APPLICATION OF THE EQUATION

Once the values for the independent variables have been determined, site index can be accurately and rapidly determined from Table 2 or computed directly from the equation by a pocket calculator or with simple additions and multiplications.

Measuring the independent variables

Six values are needed to compute site index. Aspect (X_3) and position on slope (X_5) can be obtained from USGS topographic sheets or by field measurements. Thickness of the A_1 soil horizon (X_1), slope shape (b_0), and slope gradient (X_2) must be determined onsite. Precipitation (X_4) is determined easily from the map (Fig. 4). Determinations are made as follows:

Thickness of the A_1 soil horizon (X_1). The A_1 horizon consists of the uppermost layer of mineral soil. It lies just beneath the litter and humus layers, and is partly mineral (soil) and partly organic. This horizon can be distinguished from the soil horizon directly beneath it by its darker color and higher content of organic matter. And it can be distinguished from the overlying humus, which has no mineral soil (in some soils there will not be a humus layer).

The A_1 thickness varies considerably from point to point—even within short distances—so a number of determinations *must* be made. The number of samples required for good average estimates cannot be predetermined, since sampling requirements depend on the size of the area for which site index is being predicted and upon the soil heterogeneity.

As a general sampling guide, we suggest that approximately 15 determinations be made for each 10 acres if the area is relatively uniform. For larger acreages, and for those that are heterogeneous, more samples will be necessary. The final estimate should represent the mean A_1 thickness to the nearest half inch. Measurements can be made rapidly with a punch-tube soil auger in a random traverse over the area; however, it is important that a representative average for the entire tract be obtained.

Slope gradient (X_2). Determine the average slope steepness with a hand level to the nearest 10 percent slope. Divide percent slope by 100 for use in the equation.

Aspect (X_3). Aspect refers to the orientation of the site facing downslope perpendicular to the contour. Obtain the azimuth with a hand compass or from a USGS topographic sheet. If the equation is to be used for the computation, use the proper transformed cosine value from Table 3.

Precipitation (X_4). Use the average precipitation for the site to the nearest inch as shown on the map in Figure 4. For precipitation levels greater than 44 inches, use 44 in the equation and in the site index table.

Position on slope (X_5). Slope position is the distance from the plot to the ridge expressed as a percentage of total slope length. Areas located near the top of a slope have values approaching zero and those near the bottom of the slope, approaching 100. Total slope length and distance to the slope crest can usually be estimated near enough for practical purposes without the need for actual measurements.

Slope shape (b_0). Visually estimate the overall landform—whether the slope is convex, linear, or concave in a lateral direction. In the equation, assign a value of -58.761 for convex slopes, -55.988 for linear slopes, and -52.377 for concave slopes.

An example

To illustrate how to use the equation, assume that the following data were obtained from a forest site in Doddridge County:

b_0 = slope shape—linear (use -55.988).

X_1 = thickness of A_1 soil horizon—2 inches (onsite determination).

X_2 = slope gradient—30 percent slope = 30/100 = 0.30 (onsite determination). For slopes greater than 50 percent, use 0.50 as the gradient in Table 2.

X_3 = aspect—Az. 45° = 0.8090. Azimuth determined onsite or from USGS maps. Cosine values for use with the equation are in Table 3. Use the azimuth value in Tables 2 and 3 that is nearest the actual value.

X_4 = Precipitation—47 inches (Fig. 4). Since precipitation exceeds the maximum permitted, use 44 in the equation or enter the site index table at the 44-inch precipitation level.

X_5 = Position on slope—25 percent downslope (determined onsite or from USGS maps).

Estimating site index by Tabe 2. Table 2 is arranged for easy field reference, with site index predictions for aspect, A_1 thickness, position on slope, and slope shape for three slope gradients by 1-inch precipitation increments. To use the table, first select the slope gradient that is nearest to the field estimate, then select the proper precipitation rate and determine the site index that corresponds with the proper aspect, A_1 thickness, position on slope, and lateral slope shape of the tract. Extrapolation of site index for untabulated independent variable values can easily be made, if needed.

For this first example, locate the tabulations in Table 2 that correspond to a slope gradient of 0.30 and a precipitation level of 44 inches. Since the area for which site index is being estimated has an azimuth of 45° and an A_1 thickness of 2 inches, enter the table on line 6 and move to the second column that represents linear landforms on the upper 25 percent of slopes. The predicted site index is 75.

Using a different plot located on a linear slope with a gradient of 0.30, azimuth of 45°, precipitation of 44 inches, but with a 3-inch A_1 thickness and situated near the base of the slope, the site index would be 84 (Table 2).

Estimating site index with the equation. For the first example, substitute the values for the independent variables in the equation, multiply each coefficient by the proper value, and then algebraically sum the resulting figures. Thus, to compute a site index with the equation, substitute −55.988 for slope shape, 2 inches for A_1, 0.30 for slope gradient, 0.8090 for 45° azimuth (obtained from Table 3), 44 inches for precipitation, and 25 for slope position.

$$\begin{aligned}\text{Site index} = &- \text{slope shape} \\ &+ 2.897\ (A_1 \text{ thickness}) \\ &+ 7.026\ (\text{percent slope}/100) \times \text{Cos}\ (\text{azimuth}) \\ &- 9.216\ (\text{percent slope}/100) \\ &+ 2.859\ (\text{precipitation}) \\ &+ 0.081\ (\text{position})\end{aligned}$$

$$\text{Site index} = -55.988 + 2.897 \times 2 + (7.026 \times 0.30 \times 0.8090) - 9.216 \times 0.30 + 2.859 \times 44 + 0.081 \times 25$$

$$\text{Site index} = 76.6$$

The discrepancy between calculated and tabulated site indexes is due to rounding and from computing the values for the midpoints of the four slope positions for Table 2. Thus, values shown in Table 2 for the upper 25 percent portion of slopes are calculated for a distance 12.5 percent downslope from the ridge, those for the upper 25 to 50 percent portion actually represent the site index position that is 37.5 percent of the way down from the ridge, etc.

Precautions

To predict site index, there is no need to identify specific soils, but it is important to remember that both the equation and Table 2 were developed only for upland residual soils that are well drained. The equation and Table 2 *do not* apply to bottom lands, river terraces, or to upland soils that are not well drained, and should not be used for these situations.

Occasionally specific sites may not fit the general pattern of site quality that is indicated by the equation. In these cases the influencing factor is likely to be soil depth, since it is an important determinant of site quality but is considered only indirectly in the equation by position on slope and slope shape. Therefore, if an obviously deep soil happens to occupy an upper convex slope or if a shallow soil occurs on a steep lower slope, the predicted site index should be adjusted for soil depth. We suggest that 3 to 4 site index points be added to

the predicted value for upper slopes with deep soils, and 3 to 4 points subtracted from sites on lower slopes that have soils less than 3 feet deep.

Because the primary independent variable in the equation is the thickness of the A_1 soil horizon, the equation is not applicable to open agricultural land or to other disturbed sites where the A_1 thickness has not stabilized.

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APPENDIX

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Figure 1. The region studied includes about 3 million acres of forest land in northwestern West Virginia. Region boundaries are delineated by uniform climate, topographic configuration, and geologic formation from which the dominant soils have formed.

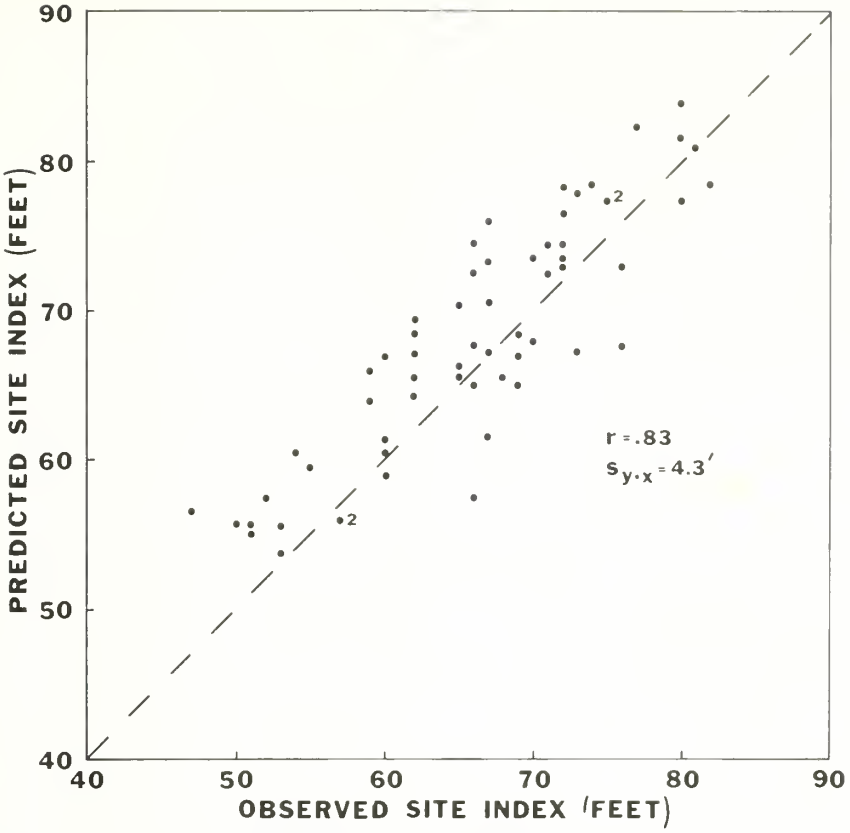

Figure 2. The relationship between predicted and observed site index for 61 independent test plots. The dashed line represents perfect 1:1 correlation. The equation overpredicts with this data set by about two site index points.

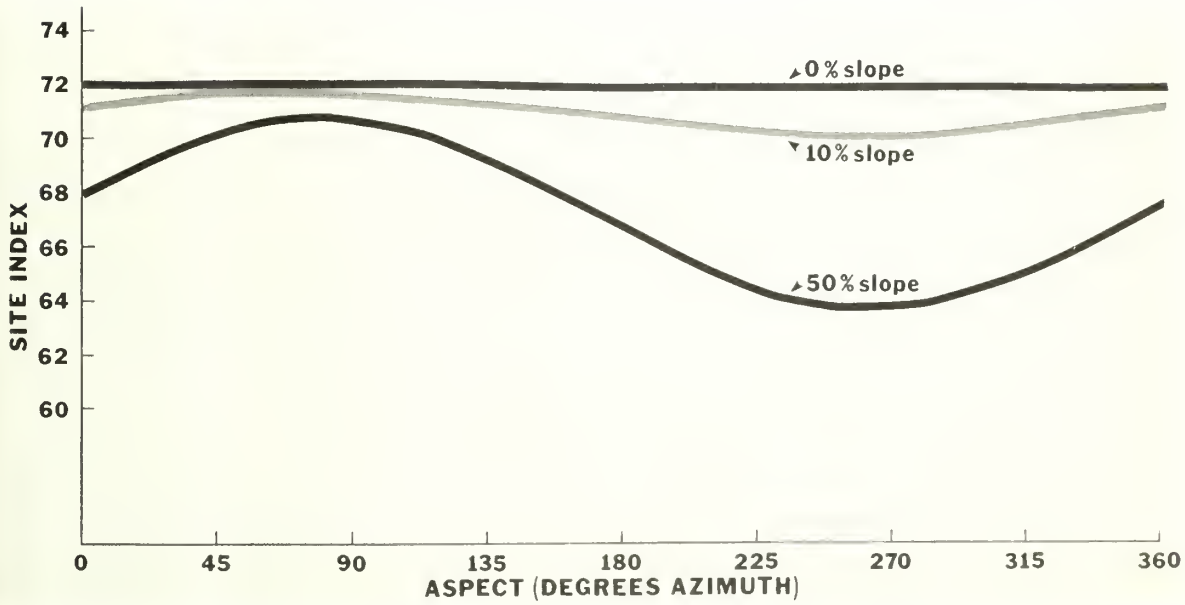

Figure 3. The relationship between site index and aspect as affected by slope gradient.

Figure 4. Average annual precipitation in the West Virginia study area.

Table 1. Oak site index values for the major upland soils within the study region[a]

Soil	Mean site index	Confidence limits (05 level)	Maximum observed site index	Minimum observed site index
Gilpin/Muskingum[b]	69	67-72	80	47
Upshur	67	63-71	80	52
Intergrades	70	67-72	85	55

[a]Includes 28 plots on Gilpin/Muskingum series, 19 plots on Upshur series, and 44 plots on integrades. For each soil, plots were distributed to encompass about equally all aspects, slope positions, and slope shapes, as well as being relatively evenly spaced over the entire study region.

[b]Gilpin /Muskingum series were combined because the sample was small for each series and their site index values were very similar.

Table 2. Predicted oak site index by slope gradient (.10, .30, .50) and precipitation (40 to 44 inches) in relation to azimuth, A_1 soil horizon thickness, position on slope, and lateral slope shape

Azimuth	A_1 depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave
		SLOPE GRADIENT = 0.10						PRECIPITATION = 40					
0	1	58	61	65	60	63	67	62	65	69	64	67	71
0	2	61	64	67	63	66	69	65	68	72	67	70	74
0	3	64	67	70	66	69	72	68	71	74	70	73	76
0	4	67	70	73	69	72	75	71	74	77	73	76	79
45	1	59	61	65	61	63	67	63	65	69	65	67	71
45	2	62	64	68	64	66	70	66	68	72	68	70	74
45	3	64	67	71	66	69	73	68	71	75	71	73	77
45	4	67	70	74	69	72	76	71	74	78	73	76	80
90	1	59	62	65	61	64	67	63	66	69	65	68	71
90	2	62	64	68	64	66	70	66	68	72	68	71	74
90	3	65	67	71	67	69	73	69	71	75	71	73	77
90	4	67	70	74	69	72	76	72	74	78	74	76	80
135	1	58	61	65	61	63	67	63	65	69	65	67	71
135	2	61	64	68	63	66	70	65	68	72	67	70	74
135	3	64	67	71	66	69	73	68	71	75	70	73	77
135	4	67	70	74	69	72	76	71	74	78	73	76	80
180	1	58	61	64	60	63	66	62	65	68	64	67	70
180	2	61	64	67	63	66	69	65	68	71	67	70	73
180	3	64	67	70	66	69	72	68	71	74	70	73	76
180	4	67	69	73	69	71	75	71	73	77	73	75	79
225	1	58	60	64	60	62	66	62	64	68	64	66	70
225	2	60	63	67	62	65	69	64	67	71	66	69	73
225	3	63	66	70	65	68	72	67	70	74	69	72	76
225	4	66	69	73	68	71	75	70	73	77	72	75	79
270	1	57	60	64	59	62	66	61	64	68	63	66	70
270	2	60	63	67	62	65	69	64	67	71	66	69	73
270	3	63	66	70	65	68	72	67	70	74	69	72	76
270	4	66	69	72	68	71	74	70	73	77	72	75	79
315	1	58	60	64	60	62	66	62	64	68	64	67	70
315	2	61	63	67	63	65	69	65	67	71	67	69	73
315	3	63	66	70	65	68	72	68	70	74	70	72	76
315	4	66	69	73	68	71	75	70	73	77	72	75	79

CONTINUED

Table 2.—Continued

Azimuth	A_1 depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave
		SLOPE GRADIENT = 0.10						PRECIPITATION = 41					
0	1	61	64	67	63	66	69	65	68	71	67	70	73
0	2	64	67	70	66	69	72	68	71	74	70	73	76
0	3	67	70	73	69	72	75	71	74	77	73	76	79
0	4	70	73	76	72	75	78	74	77	80	76	79	82
45	1	62	64	68	64	66	70	66	68	72	68	70	74
45	2	64	67	71	66	69	73	68	71	75	70	73	77
45	3	67	70	74	69	72	76	71	74	78	73	76	80
45	4	70	73	77	72	75	79	74	77	81	76	79	83
90	1	62	64	68	64	66	70	66	68	72	68	70	74
90	2	65	67	71	67	69	73	69	71	75	71	73	77
90	3	67	70	74	69	72	76	71	74	78	73	76	80
90	4	70	73	77	72	75	79	74	77	81	76	79	83
135	1	61	64	68	63	66	70	65	68	72	67	70	74
135	2	64	67	71	66	69	73	68	71	75	70	73	77
135	3	67	70	74	69	72	76	71	74	78	73	76	80
135	4	70	73	76	72	75	78	74	77	80	76	79	82
180	1	61	64	67	63	66	69	65	68	71	67	70	73
180	2	64	66	70	66	69	72	68	71	74	70	73	76
180	3	67	69	73	69	71	75	71	73	77	73	75	79
180	4	70	72	76	72	74	78	74	76	80	76	78	82
225	1	60	63	67	62	65	69	64	67	71	66	69	73
225	2	63	66	70	65	68	72	67	70	74	69	72	76
225	3	66	69	73	68	71	75	70	73	77	72	75	79
225	4	69	72	75	71	74	77	73	76	79	75	78	82
270	1	60	63	67	62	65	69	64	67	71	66	69	73
270	2	63	66	70	65	68	72	67	70	74	69	72	76
270	3	66	69	72	68	71	74	70	73	76	72	75	78
270	4	69	72	75	71	74	77	73	76	79	75	78	81
315	1	61	63	67	63	65	69	65	67	71	67	69	73
315	2	63	66	70	65	68	72	67	70	74	69	72	76
315	3	66	69	73	68	71	75	70	73	77	72	75	79
315	4	69	72	76	71	74	78	73	76	80	75	78	82

CONTINUED

Table 2.—Continued

Azimuth	A_1 depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave
		SLOPE GRADIENT = 0.10						PRECIPITATION = 42					
0	1	64	67	70	66	69	72	68	71	74	70	73	76
0	2	67	70	73	69	72	75	71	74	77	73	76	79
0	3	70	72	76	72	75	78	74	77	80	76	79	82
0	4	73	75	79	75	77	81	77	79	83	79	81	85
45	1	64	67	71	66	69	73	68	71	75	70	73	77
45	2	67	70	74	69	72	76	71	74	78	73	76	80
45	3	70	73	77	72	75	79	74	77	81	76	79	83
45	4	73	76	79	75	78	81	77	80	83	79	82	86
90	1	64	67	71	67	69	73	69	71	75	71	73	77
90	2	67	70	74	69	72	76	71	74	78	73	76	80
90	3	70	73	77	72	75	79	74	77	81	76	79	83
90	4	73	76	80	75	78	82	77	80	84	79	82	86
135	1	64	67	71	66	69	73	68	71	75	70	73	77
135	2	67	70	73	69	72	76	71	74	78	73	76	80
135	3	70	73	76	72	75	78	74	77	80	76	79	82
135	4	73	76	79	75	78	81	77	80	83	79	82	85
180	1	64	66	70	66	68	72	68	70	74	70	73	76
180	2	67	69	73	69	71	75	71	73	77	73	75	79
180	3	69	72	76	72	74	78	74	76	80	76	78	82
180	4	72	75	79	74	77	81	76	79	83	78	81	85
225	1	63	66	70	65	68	72	67	70	74	69	72	76
225	2	66	69	73	68	71	75	70	73	77	72	75	79
225	3	69	72	75	71	74	77	73	76	79	75	78	81
225	4	72	75	78	74	77	80	76	79	82	78	81	84
270	1	63	66	69	65	68	72	67	70	74	69	72	76
270	2	66	69	72	68	71	74	70	73	76	72	75	78
270	3	69	72	75	71	74	77	73	76	79	75	78	81
270	4	72	75	78	74	77	80	76	79	82	78	81	84
315	1	63	66	70	65	68	72	67	70	74	69	72	76
315	2	66	69	73	68	71	75	70	73	77	72	75	79
315	3	69	72	76	71	74	78	73	76	80	75	78	82
315	4	72	75	78	74	77	80	76	79	83	78	81	85

CONTINUED

Table 2.—Continued

Azimuth	A_1 depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave
		SLOPE GRADIENT = 0.10						PRECIPITATION = 43					
0	1	67	70	73	69	72	75	71	74	77	73	76	79
0	2	70	72	76	72	74	78	74	76	80	76	79	82
0	3	73	75	79	75	77	81	77	79	83	79	81	85
0	4	75	78	82	77	80	84	80	82	86	82	84	88
45	1	67	70	74	69	72	76	71	74	78	73	76	80
45	2	70	73	77	72	75	79	74	77	81	76	79	83
45	3	73	76	79	75	78	81	77	80	83	79	82	85
45	4	76	79	82	78	81	84	80	83	86	82	85	88
90	1	67	70	74	69	72	76	71	74	78	73	76	80
90	2	70	73	77	72	75	79	74	77	81	76	79	83
90	3	73	76	80	75	78	82	77	80	84	79	82	86
90	4	76	79	82	78	81	84	80	83	86	82	85	88
135	1	67	70	73	69	72	75	71	74	77	73	76	80
135	2	70	73	76	72	75	78	74	77	80	76	79	82
135	3	73	76	79	75	78	81	77	80	83	79	82	85
135	4	76	79	82	78	81	84	80	83	86	82	85	88
180	1	67	69	73	69	71	75	71	73	77	73	75	79
180	2	69	72	76	71	74	78	73	76	80	76	78	82
180	3	72	75	79	74	77	81	76	79	83	78	81	85
180	4	75	78	82	77	80	84	79	82	86	81	84	88
225	1	66	69	72	68	71	74	70	73	77	72	75	79
225	2	69	72	75	71	74	77	73	76	79	75	78	81
225	3	72	75	78	74	77	80	76	79	82	78	81	84
225	4	75	78	81	77	80	83	79	82	85	81	84	87
270	1	66	69	72	68	71	74	70	73	76	72	75	78
270	2	69	72	75	71	74	77	73	76	79	75	78	81
270	3	72	75	78	74	77	80	76	79	82	78	81	84
270	4	75	77	81	77	79	83	79	81	85	81	83	87
315	1	66	69	73	68	71	75	70	73	77	72	75	79
315	2	69	72	76	71	74	78	73	76	80	75	78	82
315	3	72	75	78	74	77	80	76	79	82	78	81	84
315	4	75	78	81	77	80	83	79	82	85	81	84	87

CONTINUED

Table 2.—Continued

Azimuth	A_1 depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave
		SLOPE GRADIENT = 0.10						PRECIPITATION = 44					
0	1	70	72	76	72	74	78	74	76	80	76	78	82
0	2	73	75	79	75	77	81	77	79	83	79	81	85
0	3	75	78	82	77	80	84	79	82	86	81	84	88
0	4	78	81	85	80	83	87	82	85	89	84	87	91
45	1	70	73	76	72	75	78	74	77	81	76	79	83
45	2	73	76	79	75	78	81	77	80	83	79	82	85
45	3	76	79	82	78	81	84	80	83	86	82	85	88
45	4	79	82	85	81	84	87	83	86	89	85	88	91
90	1	70	73	77	72	75	79	74	77	81	76	79	83
90	2	73	76	79	75	78	82	77	80	84	79	82	86
90	3	76	79	82	78	81	84	80	83	86	82	85	88
90	4	79	82	85	81	84	87	83	86	89	85	88	91
135	1	70	73	76	72	75	78	74	77	80	76	79	82
135	2	73	76	79	75	78	81	77	80	83	79	82	85
135	3	76	78	82	78	81	84	80	83	86	82	85	88
135	4	79	81	85	81	83	87	83	85	89	85	87	91
180	1	69	72	76	71	74	78	73	76	80	75	78	82
180	2	72	75	79	74	77	81	76	79	83	78	81	85
180	3	75	78	82	77	80	84	79	82	86	81	84	88
180	4	78	81	84	80	83	86	82	85	89	84	87	91
225	1	69	72	75	71	74	77	73	76	79	75	78	81
225	2	72	75	78	74	77	80	76	79	82	78	81	84
225	3	75	78	81	77	80	83	79	82	85	81	84	87
225	4	78	80	84	80	82	86	82	84	88	84	86	90
270	1	69	72	75	71	74	77	73	76	79	75	78	81
270	2	72	74	78	74	77	80	76	79	82	78	81	84
270	3	75	77	81	77	79	83	79	81	85	81	83	87
270	4	78	80	84	80	82	86	82	84	88	84	86	90
315	1	69	72	75	71	74	78	73	76	80	75	78	82
315	2	72	75	78	74	77	80	76	79	82	78	81	84
315	3	75	78	81	77	80	83	79	82	85	81	84	87
315	4	78	81	84	80	83	86	82	85	88	84	87	90

CONTINUED

Table 2.—Continued

Azimuth	A_1 depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave
		SLOPE GRADIENT = 0.30						PRECIPITATION = 40					
0	1	57	59	63	59	61	65	61	63	67	63	65	69
0	2	59	62	66	61	64	68	64	66	70	66	68	72
0	3	62	65	69	64	67	71	66	69	73	68	71	75
0	4	65	68	72	67	70	74	69	72	76	71	74	78
45	1	58	61	64	60	63	66	62	65	68	64	67	70
45	2	61	64	67	63	66	69	65	68	71	67	70	73
45	3	64	67	70	66	69	72	68	71	74	70	73	76
45	4	67	69	73	69	71	75	71	73	77	73	75	79
90	1	58	61	65	60	63	67	62	65	69	64	67	71
90	2	61	64	68	63	66	70	65	68	72	67	70	74
90	3	64	67	70	66	69	73	68	71	75	70	73	77
90	4	67	70	73	69	72	75	71	74	77	73	76	79
135	1	57	60	64	59	62	66	62	64	68	64	66	70
135	2	60	63	67	62	65	69	64	67	71	66	69	73
135	3	63	66	70	65	68	72	67	70	74	69	72	76
135	4	66	69	73	68	71	75	70	73	77	72	75	79
180	1	56	59	62	58	61	64	60	63	66	62	65	68
180	2	59	62	65	61	64	67	63	66	69	65	68	71
180	3	62	64	68	64	66	70	66	69	72	68	71	74
180	4	65	67	71	67	69	73	69	71	75	71	73	77
225	1	55	57	61	57	59	63	59	61	65	61	63	67
225	2	57	60	64	59	62	66	61	64	68	63	66	70
225	3	60	63	67	62	65	69	64	67	71	66	69	73
225	4	63	66	70	65	68	72	67	70	74	69	72	76
270	1	54	57	61	56	59	63	58	61	65	60	63	67
270	2	57	60	63	59	62	65	61	64	67	63	66	69
270	3	60	63	66	62	65	68	64	67	70	66	69	72
270	4	63	66	69	65	68	71	67	70	73	69	72	75
315	1	55	58	61	57	60	63	59	62	65	61	64	67
315	2	58	61	64	60	63	66	62	65	68	64	67	70
315	3	61	64	67	63	66	69	65	68	71	67	70	73
315	4	64	66	70	66	68	72	68	71	74	70	73	76

CONTINUED

Table 2.—Continued

Azimuth	A_1 depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave
		SLOPE GRADIENT = 0.30						PRECIPITATION = 41					
0	1	59	62	66	61	64	68	63	66	70	65	68	72
0	2	62	65	69	64	67	71	66	69	73	68	71	75
0	3	65	68	72	67	70	74	69	72	76	71	74	78
0	4	68	71	75	70	73	77	72	75	79	74	77	81
45	1	61	64	67	63	66	69	65	68	71	67	70	73
45	2	64	66	70	66	68	72	68	71	74	70	73	76
45	3	67	69	73	69	71	75	71	73	77	73	75	79
45	4	70	72	76	72	74	78	74	76	80	76	78	82
90	1	61	64	68	63	66	70	65	68	72	67	70	74
90	2	64	67	70	66	69	72	68	71	74	70	73	77
90	3	67	70	73	69	72	75	71	74	77	73	76	79
90	4	70	73	76	72	75	78	74	77	80	76	79	82
135	1	60	63	67	62	65	69	64	67	71	66	69	73
135	2	63	66	70	65	68	72	67	70	74	69	72	76
135	3	66	69	73	68	71	75	70	73	77	72	75	79
135	4	69	72	75	71	74	77	73	76	79	75	78	81
180	1	59	62	65	61	64	67	63	66	69	65	68	71
180	2	62	64	68	64	66	70	66	68	72	68	70	74
180	3	65	67	71	67	69	73	69	71	75	71	73	77
180	4	67	70	74	69	72	76	71	74	78	74	76	80
225	1	57	60	64	59	62	66	61	64	68	63	66	70
225	2	60	63	67	62	65	69	64	67	71	66	69	73
225	3	63	66	70	65	68	72	67	70	74	69	72	76
225	4	66	69	72	68	71	74	70	73	76	72	75	79
270	1	57	60	63	59	62	65	61	64	67	63	66	69
270	2	60	63	66	62	65	68	64	67	70	66	69	72
270	3	63	66	69	65	68	71	67	70	73	69	72	75
270	4	66	68	72	68	71	74	70	73	76	72	75	78
315	1	58	61	64	60	63	66	62	65	68	64	67	70
315	2	61	64	67	63	66	69	65	68	71	67	70	73
315	3	64	66	70	66	68	72	68	70	74	70	72	76
315	4	67	69	73	69	71	75	71	73	77	73	75	79

CONTINUED

Table 2.—Continued

Azimuth	A_1 depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave
		SLOPE GRADIENT = 0.30						PRECIPITATION = 42					
0	1	62	65	69	64	67	71	66	69	73	68	71	75
0	2	65	68	72	67	70	74	69	72	76	71	74	78
0	3	68	71	74	70	73	76	72	75	79	74	77	81
0	4	71	74	77	73	76	79	75	78	81	77	80	83
45	1	64	66	70	66	68	72	68	70	74	70	72	76
45	2	67	69	73	69	71	75	71	73	77	73	75	79
45	3	69	72	76	71	74	78	74	76	80	76	78	82
45	4	72	75	79	74	77	81	76	79	83	78	81	85
90	1	64	67	70	66	69	72	68	71	74	70	73	76
90	2	67	70	73	69	72	75	71	74	77	73	76	79
90	3	70	73	76	72	75	78	74	77	80	76	79	82
90	4	73	76	79	75	78	81	77	80	83	79	82	85
135	1	63	66	70	65	68	72	67	70	74	69	72	76
135	2	66	69	72	68	71	74	70	73	77	72	75	79
135	3	69	72	75	71	74	77	73	76	79	75	78	81
135	4	72	75	78	74	77	80	76	79	82	78	81	84
180	1	62	64	68	64	66	70	66	68	72	68	70	74
180	2	65	67	71	67	69	73	69	71	75	71	73	77
180	3	67	70	74	69	72	76	71	74	78	73	76	80
180	4	70	73	77	72	75	79	74	77	81	76	79	83
225	1	60	63	67	62	65	69	64	67	71	66	69	73
225	2	63	66	70	65	68	72	67	70	74	69	72	76
225	3	66	69	72	68	71	74	70	73	76	72	75	78
225	4	69	72	75	71	74	77	73	76	79	75	78	81
270	1	60	63	66	62	65	68	64	67	70	66	69	72
270	2	63	66	69	65	68	71	67	70	73	69	72	75
270	3	66	68	72	68	70	74	70	72	76	72	75	78
270	4	69	71	75	71	73	77	73	75	79	75	77	81
315	1	61	64	67	63	66	69	65	68	71	67	70	73
315	2	64	66	70	66	68	72	68	70	74	70	72	76
315	3	67	69	73	69	71	75	71	73	77	73	75	79
315	4	69	72	76	71	74	78	73	76	80	75	78	82

CONTINUED

Table 2.—Continued

Azimuth	A_1 depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave
		SLOPE GRADIENT = 0.30						PRECIPITATION = 43					
0	1	65	68	72	67	70	74	69	72	76	71	74	78
0	2	68	71	74	70	73	76	72	75	78	74	77	80
0	3	71	74	77	73	76	79	75	78	81	77	80	83
0	4	74	77	80	76	79	82	78	81	84	80	83	86
45	1	67	69	73	69	71	75	71	73	77	73	75	79
45	2	69	72	76	71	74	78	73	76	80	75	78	82
45	3	72	75	79	74	77	81	76	79	83	78	81	85
45	4	75	78	82	77	80	84	79	82	86	81	84	88
90	1	67	70	73	69	72	75	71	74	77	73	76	79
90	2	70	73	76	72	75	78	74	77	80	76	79	82
90	3	73	75	79	75	77	81	77	80	83	79	82	85
90	4	76	78	82	78	80	84	80	82	86	82	84	88
135	1	66	69	72	68	71	74	70	73	76	72	75	78
135	2	69	72	75	71	74	77	73	76	79	75	78	81
135	3	72	75	78	74	77	80	76	79	82	78	81	84
135	4	75	78	81	77	80	83	79	82	85	81	84	87
180	1	64	67	71	66	69	73	69	71	75	71	73	77
180	2	67	70	74	69	72	76	71	74	78	73	76	80
180	3	70	73	77	72	75	79	74	77	81	76	79	83
180	4	73	76	80	75	78	82	77	80	84	79	82	86
225	1	63	66	69	65	68	72	67	70	74	69	72	76
225	2	66	69	72	68	71	74	70	73	76	72	75	78
225	3	69	72	75	71	74	77	73	76	79	75	78	81
225	4	72	75	78	74	77	80	76	79	82	78	81	84
270	1	63	66	69	65	68	71	67	70	73	69	72	75
270	2	66	68	72	68	70	74	70	72	76	72	74	78
270	3	69	71	75	71	73	77	73	75	79	75	77	81
270	4	71	74	78	73	76	80	75	78	82	77	80	84
315	1	64	66	70	66	68	72	68	70	74	70	72	76
315	2	66	69	73	69	71	75	71	73	77	73	75	79
315	3	69	72	76	71	74	78	73	76	80	75	78	82
315	4	72	75	79	74	77	81	76	79	83	78	81	85

CONTINUED

Table 2.—Continued

Azimuth	A_1 depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave
		SLOPE GRADIENT = 0.30						PRECIPITATION = 44					
0	1	68	71	74	70	73	76	72	75	78	74	77	80
0	2	71	74	77	73	76	79	75	78	81	77	80	83
0	3	74	77	80	76	79	82	78	81	84	80	83	86
0	4	77	79	83	79	81	85	81	84	87	83	86	89
45	1	69	72	76	71	74	78	73	76	80	75	78	82
45	2	72	75	79	74	77	81	76	79	83	78	81	85
45	3	75	78	82	77	80	84	79	82	86	81	84	88
45	4	78	81	84	80	83	86	82	85	88	84	87	91
90	1	70	73	76	72	75	78	74	77	80	76	79	82
90	2	73	75	79	75	77	81	77	79	83	79	81	85
90	3	76	78	82	78	80	84	80	82	86	82	84	88
90	4	78	81	85	80	83	87	82	85	89	85	87	91
135	1	69	72	75	71	74	77	73	76	79	75	78	81
135	2	72	75	78	74	77	80	76	79	82	78	81	84
135	3	75	77	81	77	79	83	79	82	85	81	84	87
135	4	78	80	84	80	82	86	82	84	88	84	86	90
180	1	67	70	74	69	72	76	71	74	78	73	76	80
180	2	70	73	77	72	75	79	74	77	81	76	79	83
180	3	73	76	80	75	78	82	77	80	84	79	82	86
180	4	76	79	82	78	81	84	80	83	86	82	85	88
225	1	66	69	72	68	71	74	70	73	76	72	75	78
225	2	69	72	75	71	74	77	73	76	79	75	78	81
225	3	72	75	78	74	77	80	76	79	82	78	81	84
225	4	75	77	81	77	79	83	79	81	85	81	83	87
270	1	66	68	72	68	70	74	70	72	76	72	74	78
270	2	68	71	75	71	73	77	73	75	79	75	77	81
270	3	71	74	78	73	76	80	75	78	82	77	80	84
270	4	74	77	81	76	79	83	78	81	85	80	83	87
315	1	66	69	73	68	71	75	70	73	77	73	75	79
315	2	69	72	76	71	74	78	73	76	80	75	78	82
315	3	72	75	79	74	77	81	76	79	83	78	81	85
315	4	75	78	82	77	80	84	79	82	86	81	84	88

CONTINUED

Table 2.—Continued

Azimuth	A_1 depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave
SLOPE GRADIENT = 0.50								PRECIPITATION = 40					
0	1	55	58	61	57	60	63	59	62	65	61	64	67
0	2	58	61	64	60	63	66	62	65	68	64	67	70
0	3	61	64	67	63	66	69	65	68	71	67	70	73
0	4	64	66	70	66	68	72	68	70	74	70	72	76
45	1	57	60	64	59	62	66	61	64	68	63	66	70
45	2	60	63	67	62	65	69	64	67	71	66	69	73
45	3	63	66	69	65	68	71	67	70	73	69	72	75
45	4	66	69	72	68	71	74	70	73	76	72	75	78
90	1	58	61	64	60	63	66	62	65	68	64	67	70
90	2	61	64	67	63	66	69	65	68	71	67	70	73
90	3	64	66	70	66	68	72	68	70	74	70	72	76
90	4	67	69	73	69	71	75	71	73	77	73	75	79
135	1	56	59	63	58	61	65	60	63	67	63	65	69
135	2	59	62	66	61	64	68	63	66	70	65	68	72
135	3	62	65	69	64	67	71	66	69	73	68	71	75
135	4	65	68	72	67	70	74	69	72	76	71	74	78
180	1	54	57	60	56	59	62	58	61	64	60	63	66
180	2	57	59	63	59	62	65	61	64	67	63	66	69
180	3	60	62	66	62	64	68	64	66	70	66	68	72
180	4	63	65	69	65	67	71	67	69	73	69	71	75
225	1	52	54	58	54	56	60	56	58	62	58	60	64
225	2	54	57	61	56	59	63	58	61	65	60	63	67
225	3	57	60	64	59	62	66	61	64	68	63	66	70
225	4	60	63	67	62	65	69	64	67	71	66	69	73
270	1	51	54	57	53	56	59	55	58	61	57	60	63
270	2	54	57	60	56	59	62	58	61	64	60	63	66
270	3	57	59	63	59	62	65	61	64	67	63	66	69
270	4	60	62	66	62	64	68	64	66	70	66	68	72
315	1	52	55	59	54	57	61	56	59	63	58	61	65
315	2	55	58	62	57	60	64	59	62	66	61	64	68
315	3	58	61	65	60	63	67	62	65	69	64	67	71
315	4	61	64	67	63	66	69	65	68	71	67	70	73

CONTINUED

Table 2.—Continued

Azimuth	A_1 depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave
		SLOPE GRADIENT = 0.50						PRECIPITATION = 41					
0	1	58	61	64	60	63	66	62	65	68	64	67	70
0	2	61	63	67	63	66	69	65	68	71	67	70	73
0	3	64	66	70	66	68	72	68	70	74	70	72	76
0	4	67	69	73	69	71	75	71	73	77	73	75	79
45	1	60	63	66	62	65	69	64	67	71	66	69	73
45	2	63	66	69	65	68	71	67	70	73	69	72	75
45	3	66	69	72	68	71	74	70	73	76	72	75	78
45	4	69	72	75	71	74	77	73	76	79	75	78	81
90	1	61	63	67	63	66	69	65	68	71	67	70	73
90	2	64	66	70	66	68	72	68	70	74	70	72	76
90	3	67	69	73	69	71	75	71	73	77	73	75	79
90	4	69	72	76	71	74	78	73	76	80	75	78	82
135	1	59	62	66	61	64	68	63	66	70	65	68	72
135	2	62	65	69	64	67	71	66	69	73	68	71	75
135	3	65	68	71	67	70	74	69	72	76	71	74	78
135	4	68	71	74	70	73	76	72	75	78	74	77	80
180	1	57	59	63	59	61	65	61	64	67	63	66	69
180	2	60	62	66	62	64	68	64	66	70	66	68	72
180	3	62	65	69	65	67	71	67	69	73	69	71	75
180	4	65	68	72	67	70	74	69	72	76	71	74	78
225	1	54	57	61	56	59	63	58	61	65	60	63	67
225	2	57	60	64	59	62	66	61	64	68	63	66	70
225	3	60	63	67	62	65	69	64	67	71	66	69	73
225	4	63	66	69	65	68	71	67	70	74	69	72	76
270	1	54	57	60	56	59	62	58	61	64	60	63	66
270	2	57	59	63	59	61	65	61	63	67	63	66	69
270	3	60	62	66	62	64	68	64	66	70	66	68	72
270	4	62	65	69	64	67	71	67	69	73	69	71	75
315	1	55	58	62	57	60	64	59	62	66	61	64	68
315	2	58	61	64	60	63	67	62	65	69	64	67	71
315	3	61	64	67	63	66	69	65	68	71	67	70	73
315	4	64	67	70	66	69	72	68	71	74	70	73	76

CONTINUED

Table 2.—Continued

Azimuth	A_1 depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave
		SLOPE GRADIENT = 0.50						PRECIPITATION = 42					
0	1	61	63	67	63	65	69	65	67	71	67	70	73
0	2	64	66	70	66	68	72	68	70	74	70	72	76
0	3	66	69	73	68	71	75	71	73	77	73	75	79
0	4	69	72	76	71	74	78	73	76	80	75	78	82
45	1	63	66	69	65	68	71	67	70	73	69	72	75
45	2	66	69	72	68	71	74	70	73	76	72	75	78
45	3	69	72	75	71	74	77	73	76	79	75	78	81
45	4	72	74	78	74	76	80	76	78	82	78	80	84
90	1	64	66	70	66	68	72	68	70	74	70	72	76
90	2	66	69	73	68	71	75	71	73	77	73	75	79
90	3	69	72	76	71	74	78	73	76	80	75	78	82
90	4	72	75	79	74	77	81	76	79	83	78	81	85
135	1	62	65	69	64	67	71	66	69	73	68	71	75
135	2	65	68	71	67	70	73	69	72	75	71	74	78
135	3	68	71	74	70	73	76	72	75	78	74	77	80
135	4	71	74	77	73	76	79	75	78	81	77	80	83
180	1	60	62	66	62	64	68	64	66	70	66	68	72
180	2	62	65	69	64	67	71	66	69	73	69	71	75
180	3	65	68	72	67	70	74	69	72	76	71	74	78
180	4	68	71	75	70	73	77	72	75	79	74	77	81
225	1	57	60	64	59	62	66	61	64	68	63	66	70
225	2	60	63	67	62	65	69	64	67	71	66	69	73
225	3	63	66	69	65	68	71	67	70	73	69	72	75
225	4	66	69	72	68	71	74	70	73	76	72	75	78
270	1	57	59	63	59	61	65	61	63	67	63	65	69
270	2	60	62	66	62	64	68	64	66	70	66	68	72
270	3	62	65	69	64	67	71	66	69	73	68	71	75
270	4	65	68	72	67	70	74	69	72	76	71	74	78
315	1	58	61	64	60	63	66	62	65	68	64	67	71
315	2	61	64	67	63	66	69	65	68	71	67	70	73
315	3	64	67	70	66	69	72	68	71	74	70	73	76
315	4	67	70	73	69	72	75	71	74	77	73	76	79

CONTINUED

Table 2.—Continued

Azimuth	A_1 depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave
		SLOPE GRADIENT = 0.50						PRECIPITATION = 43					
0	1	64	66	70	66	68	72	68	70	74	70	72	76
0	2	66	69	73	68	71	75	70	73	77	72	75	79
0	3	69	72	76	71	74	78	73	76	80	75	78	82
0	4	72	75	79	74	77	81	76	79	83	78	81	85
45	1	66	69	72	68	71	74	70	73	76	72	75	78
45	2	69	71	75	71	74	77	73	76	79	75	78	81
45	3	72	74	78	74	76	80	76	78	82	78	80	84
45	4	75	77	81	77	79	83	79	81	85	81	83	87
90	1	66	69	73	68	71	75	70	73	77	72	75	79
90	2	69	72	76	71	74	78	73	76	80	75	78	82
90	3	72	75	79	74	77	81	76	79	83	78	81	85
90	4	75	78	82	77	80	84	79	82	86	81	84	88
135	1	65	68	71	67	70	73	69	72	75	71	74	77
135	2	68	71	74	70	73	76	72	75	78	74	77	80
135	3	71	74	77	73	76	79	75	78	81	77	80	83
135	4	74	76	80	76	79	82	78	81	84	80	83	86
180	1	62	65	69	64	67	71	66	69	73	68	71	75
180	2	65	68	72	67	70	74	69	72	76	71	74	78
180	3	68	71	75	70	73	77	72	75	79	74	77	81
180	4	71	74	77	73	76	79	75	78	82	77	80	84
225	1	60	63	67	62	65	69	64	67	71	66	69	73
225	2	63	66	69	65	68	71	67	70	73	69	72	75
225	3	66	69	72	68	71	74	70	73	76	72	75	78
225	4	69	72	75	71	74	77	73	76	79	75	78	81
270	1	60	62	66	62	64	68	64	66	70	66	68	72
270	2	62	65	69	64	67	71	66	69	73	68	71	75
270	3	65	68	72	67	70	74	69	72	76	71	74	78
270	4	68	71	75	70	73	77	72	75	79	74	77	81
315	1	61	64	67	63	66	69	65	68	71	67	70	73
315	2	64	67	70	66	69	72	68	71	74	70	73	76
315	3	67	69	73	69	72	75	71	74	77	73	76	79
315	4	70	72	76	72	74	78	74	76	80	76	78	82

CONTINUED

Table 2.—Continued

Azimuth	A_1 depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave	Convex	Linear	Concave
		SLOPE GRADIENT = 0.50						PRECIPITATION = 44					
0	1	66	69	73	68	71	75	70	73	77	72	75	79
0	2	69	72	76	71	74	78	73	76	80	75	78	82
0	3	72	75	79	74	77	81	76	79	83	78	81	85
0	4	75	78	81	77	80	83	79	82	86	81	84	88
45	1	69	71	75	71	73	77	73	75	79	75	78	81
45	2	72	74	78	74	76	80	76	78	82	78	80	84
45	3	74	77	81	76	79	83	79	81	85	81	83	87
45	4	77	80	84	79	82	86	81	84	88	83	86	90
90	1	69	72	76	71	74	78	73	76	80	75	78	82
90	2	72	75	79	74	77	81	76	79	83	78	81	85
90	3	75	78	81	77	80	83	79	82	86	81	84	88
90	4	78	81	84	80	83	86	82	85	88	84	87	90
135	1	68	71	74	70	73	76	72	75	78	74	77	80
135	2	71	74	77	73	76	79	75	78	81	77	80	83
135	3	74	76	80	76	78	82	78	80	84	80	83	86
135	4	77	79	83	79	81	85	81	83	87	83	85	89
180	1	65	68	72	67	70	74	69	72	76	71	74	78
180	2	68	71	75	70	73	77	72	75	79	74	77	81
180	3	71	74	77	73	76	79	75	78	81	77	80	83
180	4	74	77	80	76	79	82	78	81	84	80	83	86
225	1	63	66	69	65	68	71	67	70	73	69	72	75
225	2	66	69	72	68	71	74	70	73	76	72	75	78
225	3	69	72	75	71	74	77	73	76	79	75	78	81
225	4	72	74	78	74	76	80	76	78	82	78	81	84
270	1	62	65	69	64	67	71	66	69	73	68	71	75
270	2	65	68	72	67	70	74	69	72	76	71	74	78
270	3	68	71	75	70	73	77	72	75	79	74	77	81
270	4	71	74	77	73	76	79	75	78	81	77	80	83
315	1	64	67	70	66	69	72	68	71	74	70	73	76
315	2	67	69	73	69	71	75	71	73	77	73	76	79
315	3	70	72	76	72	74	78	74	76	80	76	78	82
315	4	72	75	79	74	77	81	77	79	83	79	81	85

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Table 3. Cosine values for plot azimuth having a phase shift angle of 81° (for X_3 in site index prediction equation)

Plot azimuth	X_3 value	Plot azimuth	X_3 value	Plot azimuth	X_3 value	Plot azimuth	X_3 value
N 0	0.1564	E 90	0.9877	S 180	−0.1564	W 270	−0.9877
5	.2419	95	.9703	185	−.2419	275	−.9703
10	.3256	100	.9455	190	−.3256	280	−.9455
15	.4067	105	.9135	195	−.4067	285	−.9135
20	.4848	110	.8746	200	−.4848	290	−.8746
25	.5592	115	.8270	205	−.5592	295	−.8290
30	.6293	120	.7771	210	−.6293	300	−.7771
35	.6947	125	.7193	215	−.6947	305	−.7193
40	.7547	130	.6561	220	−.7547	310	−.6561
NE 45	.8090	SE 135	.5878	SW 225	−.8090	NW 315	−.5878
50	.8572	140	.5150	230	−.8572	320	−.5150
55	.8988	145	.4384	235	−.8988	325	−.4384
60	.9336	150	.3584	240	−.9336	330	−.3584
65	.9613	155	.2756	245	−.9613	335	−.2756
70	.9816	160	.1908	250	−.9816	340	−.1908
75	.9945	165	.1045	255	−.9945	345	−.1045
80	.9998	170	.0175	260	−.9998	350	−.0175
85	.9976	175	−.0698	265	−.9976	355	.0698

List of independent variables tested for predicting oak site quality

1. Latitude—in degrees determined from USGS maps.
2. Longitude—in degrees determined from USGS maps.
3. Azimuth—in degrees.
4. Cosine of azimuth with a phase shift of 45°.
5. Cosine of azimuth with a phase shift of 58° (from Lloyd and Lemmen 1968).
6. Cosine of azimuth with a phase shift of 81°, and adjusted for slope steepness (from Stage 1976) (X_3 in equation).
7. Average slope gradient—general grade of the total slope expressed as percent rise.
8. Plot slope gradient—grade across the plot expressed as percent rise (X_2 in equation).
9. Slope length—total slope length in feet.
10. Distance to ridge—length of slope above the plot to the ridge, in feet.
11. Position on slope—distance between the plot and the ridge expressed as a percentage of total slope length (X_5 in equation).
12. Land form—slope or bench.
13. Slope shape—convex, linear, or concave (b_0 in equation).
14. Basal area—basal area per acre of stems greater than 4.5 inches dbh.
15. Thickness of A_1 horizon—average thickness of the A_1 soil horizon, in inches (X_1 in equation).
16. Thickness of A_3 horizon—average thickness of the A_3 soil horizon, in inches.
17. Thickness of A horizon—combined thickness of A_1 and A_3 soil horizons, in inches.
18. Thickness of B horizon—thickness of all B horizons, in inches.
19. Depth of solum—thickness of A and B horizons, in inches.
20. Total soil depth—depth to bedrock or 6 feet, whichever is shallowest.
21. pH of A_1 horizon—field determination.
22. pH of A_3 horizon—field determination.
23. pH of B horizon—field determination.
24. pH of C horizon—field determination.
25. Percent stones in A_1—estimated stone content of A_1 soil horizon.
26. Percent stones in A—estimated stone content of $A_1 + A_3$ soil horizons.
27. Percent stones in B—estimated stone content of B soil horizon.
28. Percent stones in C—estimated stone content of C horizon.
29. Reciprocal of stand age— $\frac{1}{\text{Stand Age}}$.
30. Growing season insolation—potential Langleys reaching the plot between May 3 and September 23.
31. Radiation index—ratio of annual radiation to the annual maximum potential solar beam irradiation.
32. Elevation—elevation of the plot above sea level in feet.
33. Rise—rise in elevation from the plot to the highest point within 5 miles, in feet.
34. Annual precipitation—estimated precipitation, in inches (from map, Fig. 4) (X_4 in equation).
35. Square of annual precipitation.
36. Cube of annual precipitation.
37. Reciprocal of annual precipitation.
38. Logarithm of annual precipitation.
39. Square root of annual precipitation.
40. Soil series—Gilpin/Muskingum, Upshur, intergrade (used as dummy variable).
41. Reciprocal of A_1 thickness— $\frac{1}{\text{Thickness of } A_1}$.
42. Reciprocal of A thickness— $\frac{1}{\text{Total thickness of } A_1 + A_3}$.
43. Reciprocal of solum depth— $\frac{1}{\text{Thickness of solum}}$.
44. Reciprocal of total soil depth— $\frac{1}{\text{Soil depth to bedrock or 6 feet}}$.
45. Regional site index—a value of site index calculated from the relationship between site index and aspect plus soil depth for West Virginia.
46. Latitude/longitude interaction — latitude multiplied by longitude.

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by John C. Bjorkbom

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Seed Production and Advance Regeneration in Allegheny Hardwood Forests

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Abstract

The production of flowers and seeds of black cherry, red maple, sugar maple, and white ash and their relation to advance regeneration were observed from 1971 through 1976 on the Allegheny Plateau of northwestern Pennsylvania. There were good seed crops 1 year out of 2 for black cherry, 1 year out of 3 for red maple, and 1 year out of 6 for sugar maple. No white ash seed was produced. Flower crops were reliable indicators of seed crop size for the maples but not for black cherry. Both seed production and advance regeneration were related to basal area. Advance regeneration and basal area data were used to develop a guide to evaluate the adequacy of seed sources for the regeneration of Allegheny hardwood stands.

INTRODUCTION

ADVANCE REPRODUCTION is the key to success in regenerating Allegheny hardwood forests with valuable species such as black cherry, red maple, sugar maple, and white ash.[1] But in many areas, advance seedlings of these species are absent. The most likely reasons for this include lack of seed source, inadequate seed production, failure of seeds to germinate, and failure of seedlings to survive.

We know in a general way how often good seed crops develop, about how much seed can be produced, and when it is dispersed (U.S. Forest Service 1974). But less is known about the relationship between flower crops and seed crops. On a broader scale, we have little data on the interdependence of forest stands, seed production, and advance regeneration. Forest managers concerned with regenerating new stands need to know how species composition affects seed production, how seed production affects the number of new seedlings, and how long seedlings survive under the canopy of a closed stand.

To learn what these relationships are, I studied the characteristics of seed production of a number of Allegheny hardwood stands and the effects of seed crops on the advance regeneration.

THE STUDY AREAS

Two areas, each about 4 acres in size, were established in hardwood stands that originated about 1900 on the Allegheny Plateau. Neither area showed evidence of recent disturbance that might affect seed production; however, there were some differences between them.

In Area 1, the stand was 96 percent stocked, had an average stand diameter of 7.4 inches, and had a total basal area per acre of 136 ft^2, of which about 40 percent was in black cherry and 35 percent was in sugar maple.[2] The remainder was in red maple (15 percent), white ash (4 percent), and other species (6 percent).

In Area 2, the stand was 99 percent stocked and had an average stand diameter of 8.5 inches. The total basal area per acre was 153 ft^2, of which nearly 50 percent was in black

[1]Scientific names of species referred to in this report are listed at the end of the paper.

[2]In both areas, this includes all trees in the 1-inch diameter class or larger.

cherry and 35 percent was in sugar maple. There was little red maple (1 percent) and no white ash. The remaining basal area (15 percent), was in other species, principally beech.

METHODS

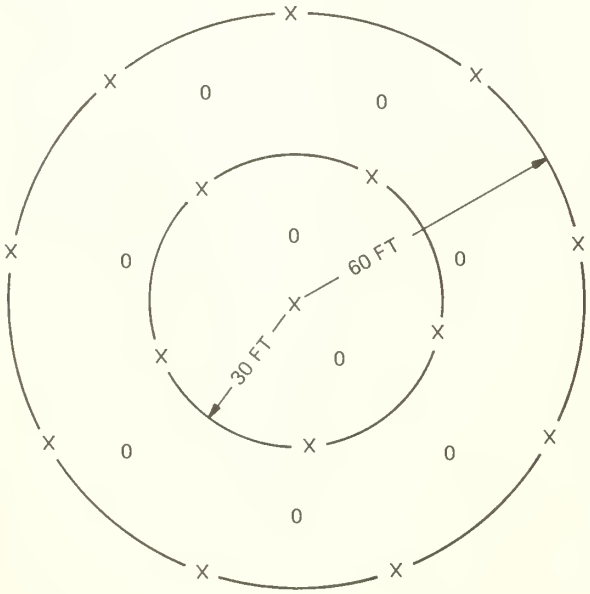
Seed production

In each area, 19 clusters of seed traps were located randomly. Distances among clusters were great enough so that little, if any, seed from a single seed tree was likely to be dispersed into more than one cluster. Each cluster was treated as a single stand.

Fifteen seed traps were systematically located in each cluster (Fig. 1). These traps were 6-inch diameter plastic flower pots fitted with perforated plastic bags. The traps, fastened to stakes, were 3 to 4 ft above the ground. To prevent seed pilferage by small mammals, 1-ft squares of aluminum were attached to the stakes (Fig. 2). Seed collections from these traps were used to estimate seed production, seed quality, and time of dispersal.

Figure 2.—A total of 285 seed traps such as this were used to estimate seed production.

Figure 1.—There are 15 seed traps (x) and 9 regeneration plots (o) in each cluster. Clusters are 60 feet in radius and encompass about 0.25 acres.



The trapping seasons covered the periods in which ripe seed was dispersed. The season for red maple extended from May 1 to June 30. For black cherry, sugar maple, and white ash, trapping began August 1 and ended November 30. During these periods, counts were made weekly from 1971 through 1973, but only at the end of the dispersal periods thereafter.

The basal area per acre of black cherry was estimated from inventories of 15-ft radius plots centered on each trap location. This radius was used because it is the crown radius of an 18-inch black cherry (Hough 1935)—the largest diameter tree that might be expected to be found with some frequency in the study stands—and the crown of this species, with its heavy seed, must overhang or be close to a trap for its seed to be caught.

Because the seeds of red maple and sugar maple are relatively light, they are dispersed much greater distances. Estimates of basal area per acre of these species were based on plots 120 ft in radius with the plot center used as the central trap location in each of the 19 clusters.

The amount of seed stored in the humus was estimated from 1-ft^2 blocks cut from the forest floor in early April. These blocks were maintained in a greenhouse where light, moisture, and temperature conditions favored seed germination. Germinants were counted by species as they appeared and, at the end of the growing season, the blocks were sieved to recover any sound ungerminated seeds.

Flower crops

Sample trees of black cherry, red maple, sugar maple, and white ash were selected in each seed production area (Table 1) for estimates of flower production. This was done to determine whether flowering estimates were good indicators of seed production.

Flower crops were rated according to the relative abundance of flowers borne on twigs or branches randomly selected in the upper crowns (Grisez 1975). Here, in my report, the crops were grouped as good to bumper, poor to fair, or trace to none. For red or sugar maple flower crops to qualify as good to bumper, more than half of the branches sampled had to have three or more flower custers. A good to bumper flower crop for black cherry averaged 33 flowers per sampled twig.

Regeneration

Regeneration tallies by species and height class of all stems below the 1-inch diameter class were made on 9 milacre plots in each of four clusters of seed traps in Area 1. The initial inventory was made in spring 1973. Thereafter, annual inventories were made at the end of each growing season from 1973 through 1976. At each inventory, seedlings were distinctively marked so that the year of origin (or age) would be known. In the May and September 1973 inventories, the number of seedlings was underestimated because the maximum number recorded was 99. Beginning with the 1974 inventory, the total number was recorded.

RESULTS AND DISCUSSION

Flower crops

Red maple flower crops were good to bumper in 4 years out of 6 from 1971 through 1976. In 1973 and 1976 there were untimely frosts that may have killed most of the flowers.

In the same period, a good to bumper black cherry flower crop was never recorded. This may have been the result of poor visibility rather than limited flowering—foliage of maple, beech, and other trees in the lower crown canopy obscured the cherry crowns that occupied dominant positions in the upper canopy. Also, there were frosts at this time and they may have destroyed the flower crops.

Table 1.—Number and diameter of sample trees by species and seed production area

Species	Area 1		Area 2	
	Number of trees	Diameter range (inches)	Number of trees	Diameter range (inches)
Black cherry	17	9.9-23.7	18	10.2-22.7
Red maple	11	9.8-16.3	5	11.9-17.9
Sugar maple	14	7.1-17.6	16	10.0-16.4
White ash	20	7.0-17.8	0	—

Sugar maple had only one good to bumper flower crop in the 6 years of observations. White ash failed to flower in that length of time.

Seed production

Seed production was not always of the same magnitude in both areas (Tables 2 and 3). This can be explained in part by differences in numbers of trees, basal area, and local weather conditions.

If the patterns of seed production reported here were to continue, good seed production for black cherry might be expected 1 year out of 2; for red maple, 1 year out of 3; and 1 year out of 6 for sugar maple. In these good seed years, seed production was estimated to average 507,000 black cherry seeds per acre and close to 450,000 seeds per acre for both red maple and sugar maple. No white ash seed was produced.

These expected frequencies of good seed years by species differ somewhat from those reported by others. Grisez (1975) reported less frequent seed years for black cherry, similar frequencies for red maple and sugar maple, and more frequent for white ash. Godman and Mattson (1976) recorded the same frequency for red maple seed years but more frequent large crops of sugar maple and white ash. The U.S. Forest Service (1974) reported greater frequencies for red maple, sugar maple, and white ash but fewer for black cherry. But the differences are small and probably arise from the dissimilar observational areas—two seed production areas for this study compared to large geographic areas or to the entire species range.

Flower vs. seed production

Red maple flower crops were good predictors of seed crops in 2 out of the 4 years in which seeds were produced—bumper flower crops were followed by abundant seed production. But in the other 2 years, good to bumper flower crops were followed by poor

Table 2.—Mean seed production per acre by species and year for Area 1[a] (thousands of seeds per acre)

Year	Black cherry	Red maple	Sugar maple
1971	78.6±69	38.0±42	1.3±208
1972	365.4±31	557.9±22	430.9±17
1973	336.6±37	0.0	0.0
1974	39.3±74	447.9±23	15.7±60
1975	597.2±25	83.8±42	0.0
1976	0.0	0.0	0.0

[a]Mean ± confidence limit in percent.

Table 3.—Mean seed production per acre by species and year for Area 2[a] (thousands of seeds per acre)

Year	Black cherry	Red maple	Sugar maple
1971	129.5±30	7.3±103	7.3±103
1972	583.5±33	408.9±12	464.2±26
1973	0.0	0.0	0.0
1974	397.3±27	112.0±53	13.1±71
1975	762.5±25	36.4±85	0.0
1976	72.8±76	0.0	0.0

[a]Mean ± confidence limit in percent.

seed years. Although the reasons for this are not clear, adverse weather may have limited pollination and fertilization; frosts may have killed many of the flowers or immature seeds. However, since flowering is followed so closely by fruiting, few benefits can be gained by predicting red maple seed crops from flower production.

Black cherry flower crops are not good indicators of the size of seed crops. Over the study period one-half of the flower crops were classed trace to none yet these flower crops were followed by seed crops that averaged an estimated 427,000 seeds per acre. In contrast, the other half of the flower crops were classed slightly better (poor to fair) and were followed by seed crops that averaged only about 103,000 seeds per acre. This disparity was the result of not only underestimated flower crops, but also the natural tendency of black cherry to flower abundantly but fruit poorly (Grisez 1975).

For sugar maple, only one flower crop was rated as good to bumper in each area, and each was followed by abundant seed. In the other 5 years, flower crops were rated trace to none and very little seed was produced. These results agree with those reported by Grisez (1975).

Seed dispersal

Seed dispersal was observed from 1971 through 1973. Almost all the red maple seed was dispersed in June, about three-fourths of the black cherry seed fell in August and September, and most of the sugar maple seed fell in October (Table 4). Seed dispersal depends on the environmental conditions under which the seed develops and matures, so the time of dispersal can—and does—vary considerably from year to year.

Seed quality

To know how much seed is produced is only part of the story. It is just as important to know how good it is. I used seed soundness as a measure of seed quality, and a sound seed was assumed to be one that has the potential to germinate.

Estimates of black cherry seed quality were made by removing the seed coat and examining the seed for evidence of any damage that might affect the viability of the seed. Maple samaras were checked for external evidence of damage and to determine whether their seeds were fully developed. Based on these observations, seed soundness for the period 1971 through 1976 was estimated to be:

Black cherry	91 percent
Red maple	82 percent
Sugar maple	56 percent

There was no statistically significant difference in seed soundness between the two areas, but it tended to be higher when seed production was high.

The percentage of sound sugar maple seed reported here agrees with similar data given by Carl and Yawney (1966). There appear to be no comparable data for either black cherry or red maple.

Seed production vs. basal area

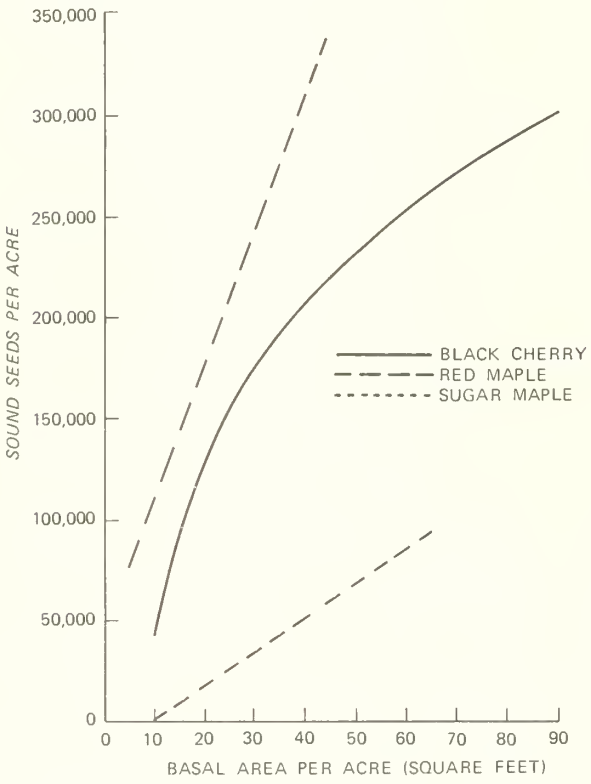
The number and size of seed trees in a stand determine how much seed can be produced. To estimate the seed production that might be expected in different stands, I used regression analysis of the average sound seed production during the 1971 through 1976

Table 4.—Percentage of total seed crop dispersed, by species, period, and year

Species and dispersal period	1971	1972	1973
Red maple			
June 1-15	0	78	—
June 16-30	98	20	—
July 1-10	2	2	—
Total	100	100	—[a]
Black cherry			
August	82	14	0
September	13	54	53
October	5	32	47
Total	100	100	100
Sugar maple			
August	—	2	—
September	—	5	—
October	—	78	—
November	—	15	—
Total	—[a]	100	—[a]

[a]Seed crop too small for reliable estimate.

Figure 3.—Average sound seed production per acre from 1971 through 1976. Regression formulas: Red maple $R^2 = .54$, $Y = 44890 + 6461.6 X$; Black cherry $R^2 = .15$, $Y = -223980 + 268710 \log X$; Sugar maple $R^2 = .25$, $Y = -15176 + 1674.6 X$.



period and the basal area per acre of trees in the 6-inch diameter class or larger. The 6-inch diameter limitation takes into account the influence of tree size on seed production. The regressions, plotted in Figure 3, are significant at the .10 level for black cherry and at the .05 level for the maples.

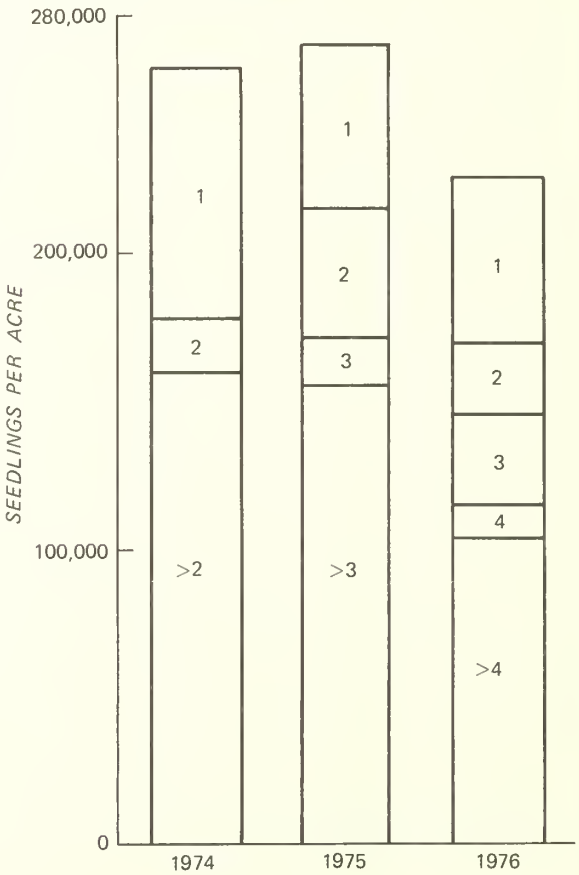
From these curves, it is evident that seed production and basal area are related for black cherry and red maple—an observation in agreement with Marquis and others (1975). Over the study period, red maple seed production increased faster with an increase in basal area than did black cherry or sugar maple. The curve for sugar maple emphasizes the low seed production of this species and suggests that this may be a major reason for its unsatisfactory regeneration.

Effect of seed production on regeneration

Large maple seed crops in one year are generally followed by a surge in maple regeneration the next year. Marquis (1975) also reports that red maple seed beneath a closed canopy lies dormant but viable through a full year. Occasionally, red maple and sugar maple seedlings may originate from a few seeds stored in the humus over a second winter. Some red maple seeds may germinate immediately after dispersal.

Black cherry responds differently. Even when little or no seed is produced, many new seedlings appear. These come from seeds stored in the humus and they mask the effect of the most recent seed crop on the current crop of new seedlings.

Figure 4.—Age-class distribution of black cherry seedlings, by year. The numbers indicate seedling age in years.



In general, the ratios of sound seed to new seedlings averaged about six to one for black cherry and red maple, and about five to one for sugar maple over the 1972 through 1976 period.

The effects of seed production on regeneration can be seen in the age-class distribution of seedlings, and the effects can be long lasting. A continued succession of good seed years means that all age classes are well represented. This situation prevails with black cherry (Fig. 4) more than with the maples.

When good seed years are periodic, then at least one age class is poorly represented. This is illustrated for red maple in Figure 5 and for sugar maple in Figure 6. A succession of inadequate seed crops can lead to poor species representation in the new stand.

Figure 5.—Age-class distribution of red maple seedlings, by year. The numbers indicate seedling age in years.

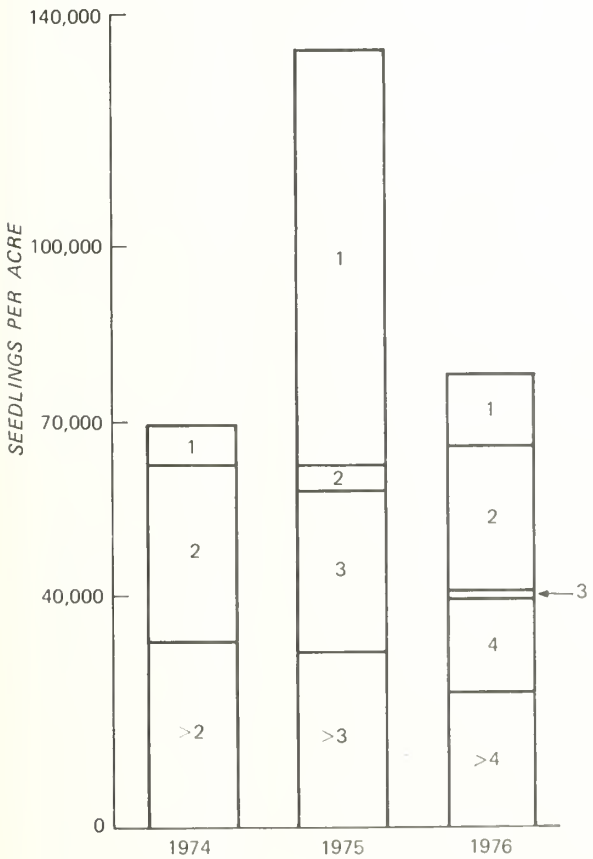
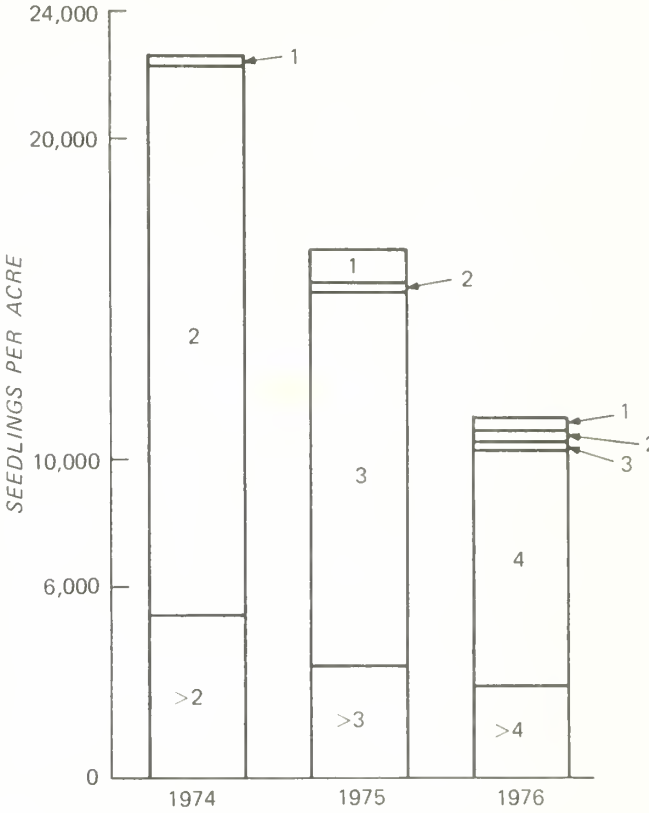


Figure 6.—Age-class distribution of sugar maple seedlings, by year. The numbers indicate seedling age in years.



Seed stored in the humus

Humus blocks cut in early spring and maintained in a greenhouse were used to estimate the amount of stored viable seed. The number of seeds varied by species and by year (Table 5). These data reflect the size of the seed crop the previous year.

The effect of stored seed is further illustrated by comparing the estimates of seed production to estimates of the number of new seedlings for selected years (Table 6).

For red maple, the very few new seedlings in 1974 point to the seed crop failure of 1973 and to the limited ability of these seeds to remain viable for more than 1 year. The same holds true for sugar maple.

Abundant black cherry regeneration appears almost every year. Even the poor seed crop of 1974 was followed by nearly as many seedlings the next year as was the large seed

Table 5.—Estimated number of sound seeds per acre stored in the humus, by species and year (thousands of seeds per acre)

Year	Red maple	Sugar maple	Black cherry
1973	313.4	94.4	319.4
1974	12.1	0.0	175.4
1975	263.8	0.0	139.2
1976	35.1	0.0	378.7

Table 6.—Estimated production of sound seeds and estimated number of seedlings in selected years

Species and year	Sound seeds per acre	Seedlings per acre
Red maple		
1972	652,400	—
1973	0	100,600
1974	432,300	6,900
1975	—	88,100
Sugar maple		
1972	254,900	—
1973	0	51,700
1974	—	200
Black cherry		
1973	426,100	—
1974	8,900	84,100
1975	—	61,000

crop of 1973. This could happen only if abundant seed was stored in a viable condition for 2 years or longer.

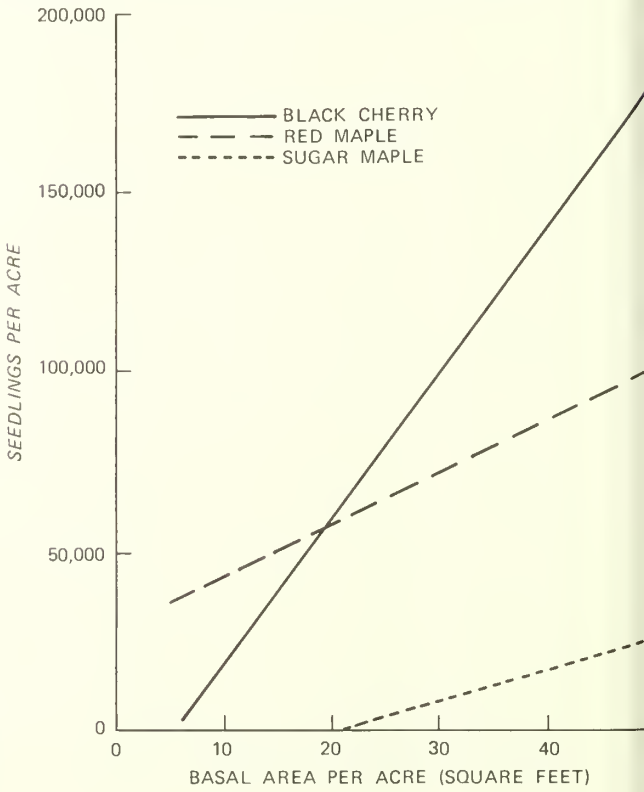
These inferences drawn from seed storage data are in agreement with observations reported by Marquis (1975) and Wendel (1977).

Effect of basal area on regeneration

To determine the relationship between advance regeneration and basal area, I used regression analysis of the average number of seedlings per acre (1974 through 1976) and the basal area per acre of black cherry, red maple, and sugar maple trees in the 6-inch diameter class or larger. The use of the average number of seedlings minimizes the effect of both bumper and failed seed crops.

Figure 7 illustrates the effect of basal area on the number of seedlings, which is best expressed as a straight-line relationship. However, there are important differences among species. For black cherry, the regression predicts a steep rise in the number of seedlings as the basal area increases. Both red and sugar maple make more moderate increases in the number of seedlings as their basal area increases. However, with the same basal area, red maple seedlings are much more abundant than sugar maple seedlings.

Figure 7.—The effect of basal area on number of seedlings. Regression formulas: Black cherry $R^2 = .58$, $Y = -22008 + 4089\ X$; Red maple $R^2 = .58$, $Y = 29581 + 1432.6\ X$; Sugar maple $R^2 = .64$, $Y = -18668 + 897.05\ X$.



USE

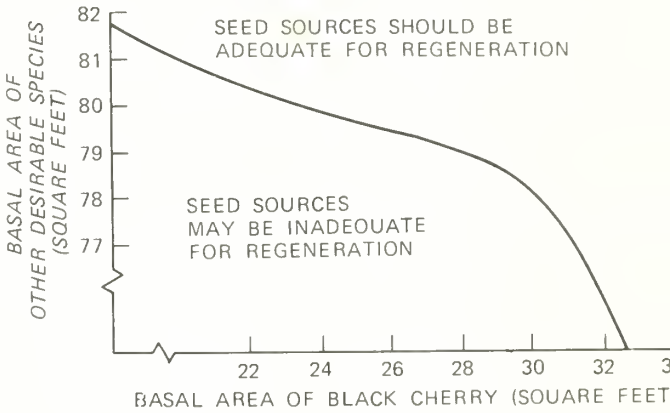
The relationship between advance regeneration and basal area can be helpful in judging the potential regenerative capacity of Allegheny hardwood stands. To further define this relationship, data reported here were supplemented with data from other regeneration studies on the Allegheny Plateau. In total, data from 42 stands were used.

The first step was to develop two regressions of the number of seedlings per acre as a function of basal area per acre. One regression was for black cherry only, the other was for the other desirable species—red maple, sugar maple, white ash, yellow-poplar, cucumbertree, and red oak. This species breakdown is required because of the impact that black cherry has on the regeneration of new stands and because its regeneration characteristics differ from those of the other desirable species. Basal area estimates were based on trees of these species 6 inches or larger in dbh.

Regeneration surveys of these 42 stands were made with the techniques described by Marquis and others (1975). Briefly, regeneration plots were classed as stocked or not stocked according to the number of black cherry seedlings and seedlings of other desirable species present. If at least 70 percent of the plots were stocked, the stand was classed as stocked. For this study, the minimum number of seedlings per plot required by the regeneration guide (Marquis and others 1975) was increased to 25 black cherry, or to any combination of black cherry and other desirable species numbering at least 100 seedlings. These increases were based on the results of field trials, and they provide a more accurate appraisal of regeneration potential.

With these advance stocking criteria, additional regressions were run that related the total number of seedlings per acre (for black cherry alone and for other desirable species as a group) to the proportion of plots with satisfactory stocking. The number of seedlings per acre required for various stocking levels were then estimated from these regressions. These values were then substituted into the first regressions to estimate the amount of overstory basal area required in each species group to obtain a given level of advance regeneration. These estimates were made for various combinations of the two species groups (e.g., 60 percent stocked with black cherry alone plus 10 percent stocked with any desirable species to total 70 percent stocked), and these values were plotted to determine seed source adequacy (Fig. 8).

Figure 8.—The intersection of the lines drawn from the basal area of black cherry and from the basal area of the other desirable species indicates the adequacy of seed sources.



To use this figure for any Allegheny hardwood stand, first determine the basal area of black cherry and of the other desirable species in the 6-inch diameter class or larger. Plot these values. If they intersect within the adequate seed source area—for example, 30 ft^2 of black cherry and 79 ft^2 of other desirable species—the assumption can be made that this stand has the potential to regenerate successfully. It does not mean that adequate advance regeneration is a certainty now or in the future. When an inadequate seed source is indicated, as for a stand with 28 ft^2 of black cherry and 78 ft^2 of other desirable species, sufficient advance regeneration is unlikely to develop. In this situation, it may be necessary to carry the stand through an extended period of thinning to develop desired species to seed-bearing size, to consider seeding or planting to augment natural regeneration, or to consider protecting seedlings from browsing by deer.

SUMMARY

The results of this study indicate that:

1. Flower crops are more reliable predictors of size of seed crop for red maple and sugar maple than for black cherry, but frequent checks must be made to detect and evaluate losses due to adverse weather, insects, or diseases.
2. Large seed crops may be expected 1 year out of 2 for black cherry, 1 year out of 3 for red maple, and 1 year out of 6 for sugar maple.
3. Seed dispersal varies from year to year but, in general, the red maple crop falls in June, black cherry in August and September, and sugar maple in October.
4. Seed soundness—the potential to germinate—tends to be higher when seed production is high. Over the study period, seed soundness averaged 91 percent for black cherry, 82 percent for red maple, 56 percent for sugar maple.
5. Most black cherry seeds do not germinate in the spring following dispersal. Such seeds remain viable in the humus for up to 3 years and are an important resource when cherry crops fail. On the other hand, few red maple and sugar maple seeds remain viable over two winters. Because of this, maple regeneration depends on the current seed crop.
6. Both seed production and advance regeneration are related to basal area. In general, a stand will be adequately stocked with black cherry regeneration if there is about 33 ft^2 of black cherry in trees 6 inches in dbh or larger. For a stand to be adequately stocked with the other desirable species, there must be about 82 ft^2 of these species in trees 6 inches in dbh or larger. These values are appropriate only on the Allegheny Plateau where large numbers of seedlings are needed to offset losses caused by deer browsing.
7. A simple method to judge the potential regenerative capacity of an Allegheny hardwood stand, based on the estimated basal areas of black cherry and of the other desirable species, has been developed.

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Common and scientific names of trees referred to in this report:

Ash, white	*Fraxinus americana* L.
Beech	*Fagus grandifolia* Ehrh.
Cherry, black	*Prunus serotina* Ehrh.
Cucumbertree	*Magnolia acuminata* L.
Maple, red	*Acer rubrum* L.
Maple, sugar	*Acer saccharum* Marsh.
Oak, northern red	*Quercus rubra* L.
Yellow-poplar	*Liriodendron tulipifera* L.

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Abstract

Results of a breeding program in which a large number of pine species were tested indicate that a number of species and hybrids may be useful in the northeastern United States. Austrian black pine x Japanese black pine and hybrids containing Japanese red pine all had good growth rates. While none of the soft pines grew faster than eastern white pine, a number of hybrids grew equally fast and the nonnative component in the crosses may provide pest resistance, which is the number one problem in the Northeast.

INTRODUCTION

IN 1947, the genetics project, located at the Morris Arboretum near Philadelphia, Pennsylvania, began an extensive hybridization program with a number of genera of trees. Reports of species crossability have been published by J. W. Wright (1948, 1953, 1958, 1959).

This paper reports on the performance of the pine hybrids at two locations: Washington Crossing State Nursery in west-central New Jersey (lat. 40°15′ N., long. 74°45′ W.) and Williamstown, Massachusetts (lat. 42°45′ N., long. 73°15′ W.).

MATERIALS AND METHODS

With few exceptions, the trees used as parents were planted specimens of unknown seed origin and were located in the Morris Arboretum and the surrounding area. Seedlots with numbers preceeded by the letter "N" were supplied by a cooperator and in most instances were not of hybrid origin. The exceptions were two lots of (*Pinus nigra* × *Pinus densiflora*) × open-pollinated seed supplied by Cold Harbor Laboratory, Long Island, New York.

A 6 × 6 foot spacing was used in all plantings at each location. A completely randomized, single-tree plot design was used in some plantations while others contained rows from a single source or a combination of the two.

All seedlings for the New Jersey planting were grown in the Washington Crossing State Nursery. Seedlings were moved to a field location adjacent to the nursery when they were 3 years old (May 1955).

Trees were measured in March, 1967, after 12 field seasons (15 years from seed), and the following information was recorded: survival, height, diameter, straightness of main stem, number of branches, multiple stems, forking of main stem or lack of apical dominance, and presence of cones.

Seedlings for the Massachusetts plantings were also grown in the New Jersey nursery and field planted in May, 1955, and May, 1956, as 2-year-old seedlings. The trees were measured in October, 1968, after either 13 or 14 field seasons (15 or 16 years from seed), and survival, height, diameter, and form were recorded for each tree. Additional information such as the presence of weevil injury, heavy fruiting, or unusual branching habits was noted for individual trees or seedlots.

RESULTS

Washington Crossing, New Jersey

Summaries of data for seedlots of section *Pinus*, subsections *Sylvestres* and *Contortae* are presented in Table 1. Seedlots with similar parentages have been combined. Individual seedlot summaries are included in Table 2.

Summaries for section *Strobus*, subsection *Cembrae*, *Strobi*, and *Cembroides* are presented in Table 3. Individual seedlot information is presented in Table 4.

The soft pines generally had good survival with the possible exception of *P. griffithii*. When *P. griffithii* was used as the female parent, survival was lower than that obtained using other species; also reduced growth was apparent. Growth of *P. strobus* × *P. griffithii* hybrids was as good as any other combination, but there was a definite reduction in growth for the reciprocal cross—*P. griffithii* × *P. strobus*. Survival and growth of selfed lots of *P. strobus* were poorer than those of outcrossed hybrids.

Survival of the hard pines was fair to good with as much variability between seedlots as between species combinations. There was reduction in survival and growth of selfed lots (*P. densiflora*, *P. thunbergiana*).

Williamstown, Massachusetts

Summaries of data for each planting at Williamstown are presented in Table 5. All species in these plantings are in section *Pinus*, subsection *Sylvestres* and *Controtae*.

The reliability of the survival figures is again dependent on the number of seedlings planted.

Seedlots with *P. sylvestris* or *P. banksiana* as the female parent generally had good survival while seedlots with *P. nigra*, *P. thunbergiana*, or *P. contorta* as the female parent had lower survival. Survival of seedlots containing *P. densiflora* was intermediate regardless of the pollen parent. The only exception to the above is that survival from *P. thunbergiana* is improved when *P. tabulaeformis* is the pollen parent—an increase of nearly 50 percent.

Seedlots with *P. nigra* and *P. thunbergiana* female parents were shorter than other combinations except for the *P. thunbergiana* × *P. tabulaeformis* combination, which produced good height growth. *P. sylvestris* and *P. densiflora* produced good height growth at this location and *P. banksiana* had excellent growth.

In the following list, seedling information is from 3- or 4-year nursery measurements previously published by Wright (1958, 1959). The "tree" information was collected in 1967 after the seedlings had been outplanted 12 seasons (15 years from seed).

P. thunbergiana × *self*. Seedlings were 10 to 50 percent shorter than crossed *P. thunbergiana*. Trees were still 20 percent smaller and survival was reduced 12 percent.

P. thunbergiana × *P. thunbergiana*. No seedling information was available. Trees were slightly smaller than most other hybrids in the New Jersey planting.

P. thunbergiana × *P. densiflora*. This cross had good seed set and seedlings were 50 percent taller than *P. thunbergiana*. This height advantage had shrunk to less than 15 percent by 1967.

P. thunbergiana × (*P. densiflora* × *P. thunbergiana*). Trees in New Jersey were 14 percent taller than *P. thunbergiana* or about the same height as *P. thunbergiana* × *P. densiflora*. Trees in Massachusetts were 19 percent taller and 13 percent larger in diameter than *P. thunbergiana*. Survival was about the same.

P. thunbergiana × *P. tabulaeformis*. Seedlings were 10 to 30 percent smaller than *P. thunbergiana*. Trees in New Jersey were 20 percent larger, and in Massachusetts trees were over 100 percent larger. Survival was also improved by 50 percent.

P. thunbergiana × *P. yunnanensis*. Seedlings were about 15 percent larger than *P. thunbergiana*, and trees in New Jersey maintained this advantage.

P. thunbergiana × *P. taiwanensis*. Seedlings were 20 percent larger than *P. thunbergiana*. This advantage had decreased to only a 12 percent difference by 1967.

P. thunbergiana × *P. massoniana*. Seedlings were 30 to 60 percent taller than *P. thunbergiana*, but the trees were less than 10 percent taller by 1967.

P. thunbergiana × *P. nigra*. Seedlings were only slightly bigger than those of *P. thunber-*

giana but the trees were 32 percent taller, 51 percent larger in diameter, and had a 36 percent survival advantage.

P. thunbergiana × *(P. thunbergiana* × *P. densiflora)*. Seedlings were slightly bigger than *P. thunbergiana*, but none was outplanted.

P. thunbergiana × *(P. nigra* × *P. densiflora)*. No information is available on seedling performance. Trees were about the same size as *P. thunbergiana*.

P. densiflora × *self*. Seedlings were 10 to 20 percent smaller than crossed *P. densiflora*. By 1967 these trees were 47 percent shorter, 60 percent smaller in diameter, and had 30 percent less survival than *P. densiflora*.

P. densiflora × *P. thunbergiana*. Seedlings were slightly larger than *P. densiflora* but trees were 33 percent shorter and 37 percent smaller in diameter.

P. densiflora × *P. sylvestris*. Seedlings were taller than *P. densiflora*. Trees were slightly smaller but survival was equally good.

P. densiflora × *(P. densiflora* × *P. sylvestris)*. No information is available on seedling growth. In New Jersey the trees were 10 to 15 percent smaller than *P. densiflora*, and in Massachusetts they were comparable.

P. densiflora × *P. nigra*. Seedlings were shorter than *P. densiflora*, but trees at both locations were about the same size as *P. densiflora*.

P. densiflora × *P. massoniana*. Seedlings were taller than *P. densiflora*. The one surviving tree was about the same size as *P. densiflora*.

P. densiflora × *(P. densiflora* × *P. thunbergiana)*. No seedling growth information is available, but trees in Massachusetts were about the same size as *P. densiflora*. In New Jersey the trees were 17 percent shorter and 34 percent smaller in diameter. Survival was about the same.

(P. densiflora × *P. thunbergiana)* × *P. thunbergiana*. Trees in New Jersey were 18 percent shorter and 50 percent smaller in diameter than *P. densiflora*. Survival percentages were similar.

(P. densiflora × *P. thunbergiana)* × *(P. densiflora* × *P. thunbergiana)*. Trees were 17 percent shorter than *P. densiflora*, but diameters were about the same. Survival was reduced by 40 percent.

P. tabulaeformis × *P. sinensis*. A comparison with *P. tabulaeformis* was not possible, but this hybrid was as good as many others in the New Jersey planting.

P. nigra × *P. thunbergiana*. Seedlings were slightly larger than *P. nigra* and trees were 10 to 15 percent larger. Survival was 40 percent better.

P. nigra × *P. densiflora*. Based on seedling performance, this is one of the best hybrids; however, trees in New Jersey were only 10 percent larger than *P. nigra*. Survival was improved by 60 percent.

P. nigra × *(P. densiflora* × *P. thunbergiana)*. No seedling information is available on this hybrid, but *P. nigra* × *(P. thunbergiana* × *P. densiflora)* seedlings were larger than *P. nigra*. Trees of these two hybrids were about the same size, and survival of *P. nigra* × *(P. densiflora* × *P. thunbergiana)* was 65 percent better than *P. nigra*.

P. nigra × *P. tabulaeformis*. Seedlings were taller than *P. nigra*, but none was outplanted.

P. sylvestris × *P. sylvestris*. No seedling information. Trees in New Jersey and Massachusetts were about the same size as other *P. sylvestris* hybrids.

P. sylvestris × *P. massoniana*. Trees were 14 percent taller and 22 percent larger in diameter than *P. sylvestris*.

P. sylvestris × *P. nigra*. Seedlings were 25 percent shorter than *P. sylvestris*, but trees in New Jersey were 10 percent taller than *P. sylvestris*.

P. sylvestris × *(P. densiflora* × *P. sylvestris)*. Seedlings were taller than *P. sylvestris*. Trees at both locations were approximately the same as *P. sylvestris*.

P. sylvestris × *(P. densiflora* × *P. thunbergiana)*. No seedling information is available, but the trees in Massachusetts were the same size as *P. sylvestris*.

P. banksiana × *P. banksiana*, *P. banksiana* × *P. contorta*, *P. banksiana* × *(P. contorta* × *P. banksiana)*. No seedling information is available. Trees in Massachusetts were very similar in height and all very good compared

to other hard pine hybrids. Survival was excellent. *P. banksiana* × OP (of questionable parentage) was 20 percent shorter and 30 percent smaller in diameter than trees of these three hybrids.

Information on soft pines was obtained only from the New Jersey planting.

P. strobus × *self*. No seedling information is available. Trees were more than 25 percent shorter and 50 percent smaller in diameter than crossed *P. strobus*. Survival was very poor compared to other crosses containing *P. strobus*.

P. strobus × *P. strobus*. Trees were as good as any hybrid in the planting.

P. strobus × *P. griffithii*. Seedlings were taller and had a larger diameter than *P. strobus*. This difference was not apparent in trees, and both the hybrid and *P. strobus* were the same size.

P. strobus × *P. flexilis*. Poor seedling growth was attributed to a poor pollen parent. Trees were still slightly shorter (13 percent) but this hybrid is not slow growing compared to others in the planting.

P. strobus × *P. koraiensis*. The hybridity of this group is questionable. The trees are as large as *P. strobus*, and it is possible that this, in fact, is the true parentage of these trees.

P. strobus × *P. ayacahuite*. Seedlings were taller than *P. strobus*, but trees were approximately the same size.

P. strobus × *P. parviflora*. Seedlings were shorter than *P. strobus*. Trees were 39 percent shorter and 49 percent smaller in diameter.

P. griffithii × *self*. None of the crosses containing *P. griffithii* female parents produced fast-growing trees. Selfing reduced height by 25 percent and diameter by 50 percent.

P. griffithii × *P. griffithii*. This is a small tree in comparison to *P. strobus*. It may be useful in pest resistance work, but it is not suitable for wood production in the New Jersey region.

P. griffithii × *P. parviflora*. The seedlings of this combination were not large and none was planted.

P. griffithii × *P. strobus*. Seedlings were taller than either *P. strobus* or *P. griffithii* and this hybrid was recommended for further evaluation. The trees were 13 percent taller than *P. griffithii*, but 30 percent shorter than *P. strobus* and the reciprocal cross *P. strobus* × *P. griffithii*.

P. ayacahuite × *P. strobus*. Seedlings were taller than *P. strobus* and about the same size as *P. strobus* × *P. ayacahuite*. There was no *P. ayacahuite* for comparison but trees of this hybrid combination were 21 percent shorter and 24 percent smaller in diameter than *P. strobus*. The reciprocal, *P. strobus* × *P. ayacahuite*, was 13 percent taller and 28 percent larger in diameter than *P. ayacahuite* × *P. strobus*.

P. ayacahuite × *P. griffithii*. Seedlings were similar in size to *P. ayacahuite* × *P. strobus* and taller than *P. strobus*. Trees were 20 percent smaller than *P. strobus* and slightly smaller than *P. ayacahuite* × *P. strobus*. Survival was the poorest of all *P. ayacahuite* hybrids.

P. ayacahuite × *P. flexilis*. Seedlings were 50 percent smaller than *P. ayacahuite* × *P. strobus*. Trees were 35 percent shorter and 23 percent smaller in diameter. Poor growth may be partially attributed to a poor *P. flexilis* pollen parent.

P. flexilis × *P. griffithii*. Seedlings were taller than either *P. flexilis* or *P. griffithii*. No trees of this combination were found in the New Jersey planting; however, the one *P. flexilis* tree is as large as any other hybrid, including those of *P. strobus*.

P. peuce × *P. strobus*. Seedlings were smaller than *P. strobus*. There were no trees in the planting; however, *P. peuce* × OP is a small tree, about one-half the size of *P. strobus*.

SUMMARY

These comments refer only to the species and hybrids included in the central New Jersey and northwestern Massachusetts plantings; seed from other sources, species, and hybrid combination could possibly outperform or underperform this entire group of plants. *Pinus resinosa* (red pine), *P. rigida* (pitch pine), and *P. echinata* (shortleaf pine) are examples of native species that might have been included for comparison purposes, and

many nonnative species were omitted.

Hybrids containing the designation "OP" are of questionable parentage, in some instances because the pollen could have come from several sources including selfing, trees of the same species, or trees of a compatible species. Comments in the Results are, therefore, limited to hybrids of known parentage, but all combinations are listed in Tables 2, 4, and 5.

This group of trees was not produced with the intent to study growth rate; in most cases they were the products of studies to determine species crossability. The parent trees were specimens available at the Morris Arboretum and in the surrounding area. They could have come from the best or the worst stands and/or parents.

In spite of these problems, a considerable amount of information on a large number of species and hybrids has been gathered. The data from these two locations should provide tree breeders with valuable information on adaptability of these species and hybrids.

A few of the hybrids and species in these plantings warrant further investigation. The use of "select" rather than "available" parents should result in even better progenies than those represented in this study.

Pinus nigra × *P. thunbergii* and the reciprocal cross looks promising and, because the natural range of both species extends above 45° N latitude, there is reason to think the hybrid would do well in many parts of the Northeast. *P. thunbergii* is a maritime species, but it has performed relatively well as a pure species at our two test sites and has done very well in hybrid combination with several other species.

Pinus densiflora extends slightly above 42° N latitude in its native range and in combination with both *P. nigra* and *P. sylvestris* as either the male or female parent, it looks very promising. Both *P. nigra* and *P. sylvestris* are found at least as far north at 50° N latitude. The variation in growth rate and stem form of *P. sylvestris* suggests that the selection of good parents in this species would yield substantial dividends in any hybrid progeny.

Pinus thunbergii × *P. tabulaeformis* and × *P. sinensis*, which is probably a form of *P. yunnanensis*, did very well in our planting and should do well in most of the region. Southern sources of *P. tabulaeformis* apparently grow faster and straighter than northern sources and if this species is as diverse as reported, parental selection would be worth the effort. *P. yunnanensis*, which is a southern species—below 30° N latitude—on mainland China, apparently does not adversely affect the growth of hybrid combinations at more northerly latitudes.

We have not yet found a soft pine that will grow as fast as the native white pine, *Pinus strobus*, in the Northeast. It appears that the greatest value of introducing new species or using them in hybrid combinations with *P. strobus* would be to increase resistance to the white pine weevil (*Pissodes strobi*) or blister rust (*Cronartium ribicola*).

The hybrid *P. strobus* × *P. griffithii* (syn *P. wallichiana* A. B. Jacks) looks as good as pure *P. strobus in our tests*. In its native range, which is restricted to higher elevations in the Himalayan Mountains (below 36° N latitude), *P. griffithii* stands are composed of tall, straight trees obviously unaffected by any major pests. Progeny tests are currently underway in New Jersey and Maine to see if this species has any resistance to the white pine weevil. If resistance is observed, hybrids or backcrosses may provide a useful solution to the major deterrent to growing soft pine in the Northeast. It is already known that *P. griffithii* has some resistance to blister rust and could be used in the North Central region with *P. strobus*, and perhaps in the West with *P. monticola*.

The other species of soft pine that responded well in these trials was *Pinus ayacahuite*. While it did not outgrow *P. strobus*, this species and hybrids containing *P. ayacahuite* grew very well in the region. Considering that the range of this species does not extend above 20° N latitude in Mexico, we were surprised by its apparent adaptation to planting sites above 40° N latitude. More information is definitely needed about variation within the species and its possible pest resistance.

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Table 1.—Washington Crossing, New Jersey—data on trees of section *Pinus* after combining seedlots of similar parentage from Table 2

Parentage ♀ ♂	Number planted	Survival (%)	Height (ft)	Diameter (in)	Tallest tree (ft)
nigra × nigra	9	22	16.5	3.5	20.0
nigra × OP	99	69	15.1	3.3	25.0
nigra × thunb	23	65	18.9	3.8	25.0
nigra × (thunb × OP)	5	80	22.7	4.5	27.0
nigra × densi	5	80	18.3	4.4	24.0
nigra × (densi × thunb)	9	89	18.4	3.5	25.0
nigra × sin	3	100	18.7	3.6	24.0
densi × self	12	67	10.5	1.4	17.0
densi × densi	24	96	19.9	3.5	28.0
densi × OP	104	75	15.6	2.7	22.0
densi × syl	12	100	18.0	3.2	26.0
densi × syl + OP	11	73	17.9	3.2	23.0
densi × (densi × syl)	38	71	15.3	2.4	23.0
densi × nigra	17	71	18.2	4.1	25.0
densi × mass	1	100	19.0	4.3	19.0
densi × thunb	13	77	13.4	2.2	18.0
densi × thunb + OP	1	100	19.0	3.0	19.0
densi × (densi × thunb)	19	79	16.6	2.3	18.0
(densi × thunb) × thunb	6	83	16.2	1.8	20.0
(densi × thunb) × OP	8	75	17.2	3.0	19.0
(densi × thunb) × (densi × thunb)	18	56	16.5	3.2	18.0
tab × OP	28	86	16.2	3.2	22.0
tab × sin	3	67	20.0	4.2	21.0
syl × syl	29	79	17.3	3.6	21.0
syl × OP	15	80	16.4	3.2	18.0
syl × mass	5	100	20.0	4.6	23.0
syl × nigra	6	86	18.8	3.8	22.0
syl × densi + OP	6	67	18.0	3.9	20.0
syl × (densi × syl)	38	95	17.4	3.4	23.0
bank × OP	40	87	19.1	4.4	23.0
bank × (cont × bank)	20	80	17.1	4.0	22.0
bank × (cont × bank) + OP	20	75	18.1	4.3	21.0
thunb × self	23	52	12.7	2.1	17.0
thunb × thunb	122	64	16.0	2.6	22.0
thunb × thunb + OP	13	69	14.3	2.2	20.0
thunb × OP	134	61	15.6	2.7	24.0
thunb × densi	80	66	18.3	3.3	26.0
thunb × (densi × thunb)	162	65	18.5	3.2	26.0
thunb × tab	114	70	20.4	3.9	28.0
thunb × tab + OP	89	88	20.9	3.9	28.0
thunb × sin	116	74	18.8	3.6	30.0
thunb × tai	3	67	18.0	3.7	23.0
thunb × mass	56	41	17.5	2.9	23.0
thunb × nigra	11	100	23.4	5.3	27.0
thunb × (nigra × densi)	1	100	18.0	4.3	18.0

Table 2.—Washington Crossing, New Jersey—performance of individual seedlots in section *Pinus*

Seedlot number	Parentage ♀ ♂	Survival (%)	Height (ft)	Diameter (in)	Form[a]	Branches[b]	Fruit[b]	Tallest tree (ft)
841	nigra × nigra	22	16.5	3.5	3.0	3.0	2.0	20.0
452	nigra × OP	83	13.4	2.8	1.8	2.4	1.0	20.0
454	nigra × OP	100	14.3	2.3	2.0	2.0	1.0	20.0
569	nigra × OP	71	17.4	3.6	1.6	2.4	1.4	22.0
754	nigra × OP	77	17.4	3.6	2.3	2.9	2.0	25.0
757	nigra × OP	75	13.0	2.0	3.0	2.0	1.0	18.0
758	nigra × OP	73	11.6	2.1	2.0	2.5	1.0	16.0
840	nigra × OP	43	15.0	2.7	3.0	2.7	2.0	17.0
846	nigra × OP	20	16.0	4.5	2.0	3.0	4.0	16.0
987	nigra × OP	60	16.3	3.9	2.0	2.7	1.0	20.0
1127	nigra × OP	75	5.7	1.7	3.0	3.0	1.0	9.0
1450	nigra × OP	33	18.0	3.2	3.0	3.0	3.0	18.0
537	nigra × thunb	75	20.7	4.6	2.0	3.0	2.0	21.0
539	nigra × thunb	100	17.7	3.1	2.7	2.3	1.3	25.0
751	nigra × thunb	100	19.1	3.5	2.3	2.6	2.0	24.0
839	nigra × thunb	40	17.5	5.0	2.5	3.0	3.0	18.0
625	nigra × (thunb × OP)	80	22.7	4.5	2.0	2.7	2.0	27.0
1135	nigra × densi	75	16.3	3.5	2.0	2.7	3.0	17.0
1141	nigra × densi	100	24.0	7.1	4.0	4.0	1.0	24.0
752	nigra × (densi × thunb)	89	18.4	3.5	2.9	3.0	2.0	25.0
755	nigra × sinensis	100	18.7	3.6	3.0	3.3	1.0	24.0
742	densi × self	33	12.0	1.1	3.0	2.0	1.0	12.0
745	densi × self	78	10.3	1.5	3.2	2.2	2.0	17.0
497	densi × densi	96	19.9	3.5	2.7	2.9	3.3	28.0
423	densi × OP	88	17.3	2.6	2.7	2.9	3.1	22.0
432	densi × OP	67	16.5	2.8	3.1	2.5	2.6	20.0
611	densi × OP	78	18.4	4.1	3.1	3.3	3.0	21.0
618	densi × OP	50	16.5	3.5	3.0	3.0	2.5	20.0
736	densi × OP	68	16.5	2.3	2.8	2.7	3.0	22.0
741	densi × OP	100	16.0	3.5	4.0	3.0	2.0	16.0
748	densi × OP	80	11.4	1.5	3.3	2.7	2.0	17.0
Neg 976	densi × OP	100	21.0	3.5	2.0	2.0	3.0	21.0
Neg 978	densi × OP	78	17.6	3.4	2.6	2.4	2.0	22.0
Neg 980	densi × OP	75	15.8	3.1	3.4	3.1	2.5	21.0
2483-48	densi × OP	100	12.0	1.7	2.0	2.0	1.0	12.0

426	densi × syl	100	19.0	3.5	3.0	3.0	4.0	19.0
495	densi × syl	100	19.6	3.9	3.0	2.6	2.4	26.0
740	densi × syl	100	16.5	2.6	3.3	3.0	3.0	24.0
434	densi × syl + OP	100	12.0	1.2	4.0	2.0	1.0	12.0
496	densi × syl + OP	83	18.4	3.6	2.8	2.8	2.2	23.0
502	densi × syl + OP	50	19.5	3.2	2.5	2.0	2.5	20.0
746	densi × (densi × syl)	75	15.5	2.6	3.1	3.0	3.0	21.0
747	densi × (densi × syl)	67	14.9	2.2	2.8	2.6	3.0	23.0
617	densi × nigra	71	18.3	4.1	3.0	3.4	2.3	25.0
743	densi × massoniana	100	19.0	1.3	3.0	2.0	1.0	19.0
1527-51	densi × thunb	77	13.4	2.2	3.1	2.7	2.0	18.0
616	densi × thunb + OP	100	19.0	3.0	4.0	2.0	4.0	19.0
610	densi × (densi × thunb)	79	16.6	2.3	3.6	2.6	3.2	18.0
614	(densi × thunb) × thunb	67	19.5	2.2	2.0	2.0	3.0	20.0
738	(densi × thunb) × thunb	100	14.0	1.6	2.7	2.0	2.0	16.0
615	(densi × thunb) × OP	75	17.2	3.0	2.8	2.7	3.3	19.0
737	(densi × thunb) × (densi × thunb)	56	16.5	3.2	3.2	2.7	3.0	18.0
733	tab × OP	95	15.9	3.1	3.0	2.7	2.0	22.0
734	tab × OP	75	17.3	4.0	2.7	3.3	1.5	20.0
834	tab × OP	100	18.0	4.8	3.0	3.0	1.0	18.0
732	tab × sin	100	20.0	4.2	2.5	3.0	2.0	21.0
619	syl × syl	60	16.7	3.7	2.5	3.5	1.3	21.0
693	syl × syl	89	17.6	3.6	2.5	3.3	2.0	21.0
694	syl × OP	88	17.3	3.4	2.7	2.7	2.0	18.0
Neg 1029	syl × OP	100	14.0	2.7	2.0	3.0	2.0	16.0
Neg 1128	syl × OP	60	16.0	2.9	3.3	3.3	2.0	17.0
697	syl × mass	100	20.0	4.6	2.8	3.4	2.0	23.0
696	syl × nigra	86	18.8	3.8	3.0	3.2	1.0	22.0
516	syl × densi + OP	67	18.0	3.9	2.7	3.5	2.0	20.0
695	syl × (densi × syl)	89	17.5	3.6	3.3	3.1	3.0	23.0
698	syl × (densi × syl)	100	17.3	3.2	2.8	3.2	2.0	23.0
568	bank × OP	84	19.0	4.5	3.2	4.0	2.8	23.0
Neg 877	bank × OP	90	19.1	4.4	3.2	3.8	3.2	21.0
762	bank × (cont × bank)	80	17.1	4.0	3.1	3.9	3.0	22.0
566	bank × (cont × bank) + OP	75	18.1	4.3	3.5	3.9	3.1	21.0

Continued

Table 2.—Continued

Seedlot number	Parentage ♀	♂	Survival (%)	Height (ft)	Diameter (in)	Form[a]	Branches[b]	Fruit[b]	Tallest tree (ft)
635	thunb × self		45	12.6	2.0	3.6	2.6	1.0	17.0
802	thunb × self		33	11.0	1.8	3.0	3.0	2.0	11.0
810	thunb × self		100	12.3	2.3	2.5	2.3	2.0	16.0
821	thunb × self		50	16.0	2.5	3.0	2.0	2.0	16.0
1163	thunb × self		100	13.0	2.0	3.0	2.0	1.0	13.0
545	thunb × thunb		100	15.5	2.5	2.5	2.3	2.0	20.0
630	thunb × thunb		73	16.6	3.0	3.3	2.3	2.0	21.0
636	thunb × thunb		60	13.0	2.0	3.0	2.7	2.0	15.0
705	thunb × thunb		59	17.1	2.5	2.9	2.1	2.0	22.0
715	thunb × thunb		40	15.6	2.4	2.8	2.4	2.0	19.0
717	thunb × thunb		60	16.6	2.6	2.5	2.1	2.0	21.0
726	thunb × thunb		79	15.3	2.8	3.2	2.7	2.0	21.0
727	thunb × thunb		71	15.8	2.5	2.8	2.5	2.0	20.0
544	thunb × thunb + OP		67	17.0	2.8	3.0	2.2	2.0	20.0
546	thunb × thunb + OP		71	12.2	1.7	3.0	2.4	1.4	15.0
540	thunb × OP		100	20.3	3.9	2.5	2.5	2.0	24.0
631	thunb × OP		55	17.0	2.7	3.3	2.5	2.0	24.0
634	thunb × OP		78	16.4	2.7	2.7	2.4	2.0	20.0
728	thunb × OP		68	14.7	2.1	2.9	2.2	2.0	19.0
789	thunb × OP		100	16.7	3.2	3.0	2.3	2.0	17.0
792	thunb × OP		50	9.0	1.0	2.0	2.0	1.0	9.0
796	thunb × OP		50	13.5	2.5	3.0	2.0	1.0	16.0
798	thunb × OP		33	16.5	2.7	3.0	3.0	2.0	19.0
799	thunb × OP		100	9.0	1.3	3.0	2.0	1.0	9.0
801	thunb × OP		50	12.3	2.2	3.0	2.3	2.0	15.0
813	thunb × OP		50	18.0	3.3	3.0	2.0	2.0	18.0
N979	thunb × OP		60	17.0	3.3	2.7	2.3	2.0	19.0
N1261	thunb × OP		78	15.5	2.8	2.9	2.4	1.6	20.0
N1262	thunb × OP		31	14.8	2.8	3.2	2.3	1.0	21.0
2167-51	thunb × OP		40	17.5	2.3	3.0	2.5	2.0	18.0
627	thunb × densi		75	16.9	2.9	2.7	2.4	2.8	24.0
628	thunb × densi		60	16.3	3.5	3.3	3.3	3.3	17.0
629	thunb × densi		55	16.3	2.8	2.8	2.5	2.0	19.0
632	thunb × densi		85	21.1	4.0	2.9	2.7	3.0	26.0
639	thunb × densi		71	22.6	4.5	3.0	2.8	3.0	26.0

791	thunb × densi	100	22.0	3.2	3.0	2.0	3.0	22.0
805	thunb × densi	50	11.0	1.5	4.0	3.2	3.0	11.0
808	thunb × densi	100	17.0	2.5	3.0	3.0	3.0	17.0
816	thunb × densi	33	19.0	4.5	4.0	4.0	4.0	19.0
822	thunb × densi	80	18.7	2.7	3.0	2.0	3.0	23.0
830	thunb × densi	50	15.5	2.2	3.0	1.5	3.0	16.0
702	thunb × (densi × thunb)	52	19.6	3.0	3.0	2.5	2.0	24.0
713	thunb × (densi × thunb)	63	17.8	2.9	3.0	2.4	2.0	24.0
723	thunb × (densi × thunb)	83	21.1	4.0	3.0	2.8	2.0	26.0
730	thunb × (densi × thunb)	85	18.3	3.7	2.9	2.6	2.0	23.0
797	thunb × (densi × thunb)	50	17.0	2.7	3.0	2.0	1.0	17.0
817	thunb × (densi × thunb)	100	20.0	4.0	3.0	2.0	1.0	20.0
633	thunb × tab	100	18.7	4.1	3.0	2.5	2.0	23.0
638	thunb × tab	63	16.9	2.7	3.0	2.2	2.0	20.0
703	thunb × tab	83	21.2	3.9	2.4	2.6	3.0	28.0
704	thunb × tab	79	21.9	4.4	2.7	3.3	2.0	27.0
714	thunb × tab	71	22.5	4.3	2.7	2.9	3.0	27.0
716	thunb × tab	53	20.5	4.1	2.5	3.1	3.0	25.0
790	thunb × tab	50	17.0	3.1	3.0	3.0	3.0	17.0
794	thunb × tab	50	21.0	3.6	2.5	2.0	2.0	24.0
803	thunb × tab	80	14.0	3.1	3.7	2.7	2.0	18.0
706	thunb × tab + OP	88	20.8	3.9	2.8	2.8	3.0	28.0
718	thunb × tab + OP	86	21.2	3.8	2.7	2.7	2.0	27.0
700	thunb × sin	30	14.9	2.5	2.9	2.6	1.0	25.0
701	thunb × sin	81	20.6	4.3	2.8	3.2	2.0	28.0
711	thunb × sin	18	14.7	2.6	3.5	2.5	1.0	19.0
712	thunb × sin	89	22.2	4.4	3.1	3.2	2.0	30.0
828	thunb × sin	100	7.0	0.6	2.0	2.0	2.0	7.0
806	thunb × tai	50	13.0	2.9	4.0	4.0	3.0	13.0
826	thunb × tai	100	23.0	4.6	3.0	2.0	1.0	23.0
710	thunb × mass	26	18.6	3.0	3.2	2.4	1.0	23.0
721	thunb × mass	44	17.6	3.1	3.2	2.7	2.0	23.0
731	thunb × mass	53	16.9	2.7	3.0	2.6	1.0	23.0
629	thunb × nigra	100	26.0	5.2	2.0	2.0	3.0	26.0
637	thunb × nigra	100	21.3	5.2	2.0	3.0	2.0	22.0
699	thunb × nigra	100	23.9	5.4	2.4	2.9	2.0	27.0
818	thunb × (nigra × densi)	100	18.0	4.3	3.0	2.0	2.0	18.0

[a]1—best; 4—poorest.
[b]1—few; 4—many.

Table 3.—Washington Crossing, New Jersey—data on trees of section *Strobus* after combining seedlots of similar parentage from Table 4

Parentage ♀	♂	Number planted	Survival (%)	Height (ft)	Diameter (in)	Tallest tree (ft)
strobus	× self	3	33	15.0	2.1	15.0
strobus	× strobus	22	87	21.4	4.1	29.0
strobus	× strobus + OP	4	100	20.7	3.8	25.0
strobus	× OP	71	80	19.1	3.8	28.0
strobus	× griffithii	44	93	21.5	4.6	29.0
strobus	× griffithii + OP	46	72	17.2	3.7	26.0
strobus	× flexilis	3	100	18.7	4.5	23.0
strobus	× koraiensis	8	87	22.1	4.4	28.0
strobus	× ayacahuite	21	81	19.6	4.3	30.0
strobus	× ayacahuite + OP	4	75	22.0	4.2	26.0
strobus	× parviflora	4	75	13.0	2.1	17.0
griffithii	× self	3	33	10.0	1.3	10.0
griffithii	× griffithii	15	53	13.5	2.6	23.0
griffithii	× griffithii + OP	94	33	12.0	2.0	24.0
griffithii	× OP	102	26	11.4	2.1	21.0
griffithii	× strobus	3	67	15.5	2.7	17.0
griffithii	× strobus + OP	51	20	12.4	2.1	17.0
griffithii	× koraiensis + OP	10	10	6.0	0.4	6.0
ayacahuite	× OP	23	78	17.3	3.2	24.0
ayacahuite	× strobus	20	65	17.0	3.1	24.0
ayacahuite	× strobus + OP	19	79	18.8	3.9	26.0
ayacahuite	× griffithii	21	43	15.2	3.6	22.0
ayacahuite	× flexilis	3	67	11.0	2.4	16.0
flexilis	× flexilis	1	100	21.0	4.1	21.0
flexilis	× OP	8	50	13.7	2.5	23.0
peuce	× OP	2	100	10.5	1.4	11.0
parviflora	× cembra + OP	2	100	11.5	1.4	13.0

Table 4.—Washington Crossing, New Jersey—performance of individual seedlots in section *Strobus*

Seedlot number	Parentage ♀	♂	Survival (%)	Height (ft)	Diameter (in)	Form[a]	Branches[b]	Fruit[b]	Tallest tree (ft)
376	strobus × self		33	15.0	2.1	2.0	1.0	1.0	15.0
365	strobus × strobus		100	23.5	4.5	1.7	2.7	1.5	29.0
366	strobus × strobus		100	21.3	4.5	2.3	2.7	1.5	25.0
389	strobus × strobus		67	21.3	3.8	2.2	2.5	2.0	27.0
390	strobus × strobus		75	17.7	2.7	2.0	2.3	2.0	21.0
370	strobus × strobus + OP		100	21.7	4.1	1.7	2.0	2.0	25.0
607	strobus × strobus + OP		100	18.0	2.8	2.0	2.0	1.0	18.0
381	strobus × OP		100	17.0	2.6	2.0	3.0	1.0	20.0
386	strobus × OP		100	24.8	4.9	2.0	2.6	2.0	28.0
392	strobus × OP		100	23.5	4.6	1.7	2.3	1.0	27.0
396	strobus × OP		100	24.0	4.6	2.0	2.0	1.0	24.0
606	strobus × OP		67	16.0	3.1	2.5	3.0	1.0	16.0
N1146	strobus × OP		63	14.4	3.0	2.3	3.1	1.5	24.0
N1156	strobus × OP		76	13.8	2.8	2.4	2.9	1.0	21.0
1957-49	strobus × OP		100	24.4	4.9	1.8	2.9	1.3	28.0
1958-49	strobus × OP		100	24.0	5.0	2.0	3.0	1.0	24.0
2146-49	strobus × OP		100	22.0	5.4	2.0	3.0	3.0	24.0
367	strobus × griffithii		94	22.7	5.2	2.1	2.9	2.0	29.0
371	strobus × griffithii		100	20.3	3.7	2.0	2.0	1.5	27.0
376	strobus × griffithii		86	16.8	3.1	2.2	2.4	1.0	24.0
382	strobus × griffithii		86	25.0	5.3	2.2	2.7	1.5	28.0
384	strobus × griffithii		100	25.3	5.0	2.0	3.0	1.0	29.0
387	strobus × griffithii		100	16.2	3.8	2.7	3.0	1.0	22.0
394	strobus × griffithii		100	24.0	5.8	2.0	2.0	2.0	27.0
596	strobus × griffithii		100	19.0	4.5	3.0	4.0	1.0	19.0
397	strobus × griffithii + OP		100	17.8	2.6	2.6	2.6	1.5	26.0
603	strobus × griffithii + OP		25	13.0	2.0	3.0	3.0	2.0	13.0
604	strobus × griffithii + OP		67	18.1	4.5	2.4	3.4	1.5	26.0
605	strobus × griffithii + OP		83	15.5	3.3	2.7	3.1	1.5	25.0
608	strobus × griffithii + OP		100	18.0	3.5	2.0	3.0	1.0	18.0
284	strobus × flexilis		100	22.0	5.8	2.0	3.0	1.0	23.0
380	strobus × flexilis		100	12.0	2.0	2.0	3.0	1.0	12.0
362	strobus × koraiensis		100	25.0	4.9	2.0	3.0	2.0	25.0
388	strobus × koraiensis		80	25.7	5.4	2.5	2.3	2.0	28.0
391	strobus × koraiensis		100	13.5	2.1	1.5	1.5	1.0	17.0
363	strobus × ayacahuite		64	16.7	3.7	2.9	3.6	1.0	19.0
369	strobus × ayacahuite		100	21.7	4.8	2.3	2.3	1.0	24.0
373	strobus × ayacahuite		100	9.5	1.3	2.0	2.0	1.0	10.0
379	strobus × ayacahuite		100	23.5	5.3	2.2	2.7	2.0	30.0

Continued

Table 4.—Continued

Seedlot number	Parentage ♀	♂	Survival (%)	Height (ft)	Diameter (in)	Form[a]	Branches[b]	Fruit[b]	Tallest tree (ft)
398	strobus × ayacahuite + OP		75	22.0	4.2	2.3	3.0	2.0	26.0
395	strobus × parviflora		75	13.0	2.1	2.3	2.3	1.0	17.0
415	griffithii × self		33	10.0	1.3	2.0	1.0	1.0	10.0
416	griffithii × griffithii		100	19.0	3.8	2.5	2.0	1.0	23.0
583	griffithii × griffithii		56	11.4	2.1	3.2	2.6	1.0	15.0
584	griffithii × griffithii		25	13.0	2.3	2.0	3.0	1.0	13.0
489	griffithii × griffithii + OP		36	11.7	1.0	2.6	2.2	1.0	18.0
491	griffithii × griffithii + OP		20	14.3	3.1	3.5	3.2	1.0	24.0
459	griffithii × OP		50	16.0	3.7	2.0	2.0	1.0	16.0
410	griffithii × OP		100	16.0	2.0	2.0	1.0	1.0	16.0
486	griffithii × OP		50	11.4	2.0	3.5	3.2	1.0	15.0
494	griffithii × OP		26	10.8	1.5	3.6	2.8	1.0	14.0
585	griffithii × OP		5	11.0	2.4	3.0	3.0	1.0	11.0
595	griffithii × OP		30	10.0	2.6	3.0	3.0	1.0	16.0
N1005	griffithii × OP		20	13.2	2.5	2.7	3.2	1.5	21.0
414	griffithii × strobus		100	14.0	2.3	1.0	2.0	1.0	14.0
581	griffithii × strobus		50	17.0	3.2	2.0	3.0	1.0	17.0
484	griffithii × strobus + OP		46	13.0	1.9	2.5	3.0	1.0	17.0
490	griffithii × strobus + OP		20	13.0	2.3	3.2	2.7	1.0	17.0
479	griffithii × koraiensis + OP		10	6.0	0.4	3.0	2.0	1.0	6.0
578	ayacahuite × OP		74	17.5	3.2	2.0	2.8	1.0	24.0
1533-50	ayacahuite × OP		100	16.5	3.2	2.7	3.0	1.0	17.0
574	ayacahuite × strobus		65	17.0	3.1	2.2	2.5	1.0	24.0
575	ayacahuite × strobus + OP		79	18.8	3.9	2.3	2.8	1.0	26.0
576	ayacahuite × griffithii		43	15.2	3.6	2.9	2.4	1.0	22.0
577	ayacahuite × flexilis		67	11.0	2.4	3.0	3.0	1.0	16.0
250	flexilis × flexilis		100	21.0	4.1	2.0	2.0	3.0	21.0
574	flexilis × OP		100	7.0	0.7	2.0	1.0	1.0	7.0
1085-47	flexilis × OP		100	9.0	0.8	2.0	1.0	1.0	7.0
1532-51	flexilis × OP		33	19.5	4.3	3.0	3.5	1.5	23.0
892	peuce × OP		100	10.5	1.4	2.0	2.0	1.0	11.0
403	parviflora × cembra + OP		100	11.5	1.4	1.5	1.0	1.0	13.0

[a]1—best; 4—poorest.
[b]1—few; 4—many.

Table 5.—Williamstown, Massachusetts—performance of individual seedlots in section *Pinus* by planting

Seedlot number	Parentage ♀ ♂	Survival (%)	Height (ft)	Diameter (in)	Form[a]	Tallest tree (ft)
	GP-02-55 (Blocks I & II)					
N1117	nigra × OP	43	11.0	1.8	3.0	14.0
N1211	nigra × OP	20	17.0	2.0	1.0	17.0
N1009	syl × OP	75	17.5	4.0	3.9	24.0
N1033	syl × OP	10	4.0	—	5.0	4.0
N1128	syl × OP	71	20.2	4.2	3.0	24.0
N1215	syl × OP	95	25.7	6.0	4.2	31.0
N976	densi × OP	62	21.6	3.9	4.4	28.0
N978	densi × OP	85	24.7	3.9	3.7	28.0
N980	densi × OP	30	—	—	5.0	—
617	densi × nigra	80	20.5	4.1	3.1	26.0
610	densi × thunb	67	20.6	3.2	4.8	24.0
N979	thunb × OP	39	19.1	3.6	3.9	24.0
638	thunb × OP	11	16.0	2.2	4.0	19.0
555	bank × bank	95	27.8	4.5	3.7	32.0
561	bank × bank	100	27.0	5.0	2.5	30.0
563	bank × bank	100	27.7	4.7	3.1	28.0
552	bank × cont	100	26.8	4.1	2.6	31.0
559	bank × cont	80	27.3	5.0	3.0	32.0
562	bank × cont	17	28.5	6.1	3.4	32.0
566	bank × cont	12	27.9	4.8	3.8	32.0
558	bank × (cont × bank)	90	26.1	3.8	2.6	31.0
565	bank × (cont × bank)	79	27.1	4.3	3.6	30.0
568	bank × (cont × bank)	95	26.3	4.0	3.5	31.0
849	cont × OP	17	24.0	3.9	3.0	24.0
850	cont × OP	25	8.0	1.8	5.0	8.0
	GP-2A-56					
693	syl × syl	85	23.1	6.0	3.9	27.0
694	syl × syl	80	22.8	5.7	3.7	27.0
698	syl × (densi × syl)	90	24.0	6.1	3.7	29.0
695	syl × (densi × thunb)	95	22.3	5.6	3.8	27.0
739	densi × OP	35	18.3	3.0	4.3	22.0
735	densi × (densi × syl)	80	18.7	3.5	4.7	25.0
747	densi × (densi × syl)	55	19.2	3.4	4.4	23.0
737	densi × (densi × thunb)	45	15.3	2.4	4.4	21.0
N1261	thunb × OP	20	8.0	0.8	5.0	9.0
705	thunb × thunb	35	11.7	1.5	5.0	15.0
715	thunb × thunb	10	9.0	1.0	5.0	9.0
717	thunb × thunb	25	10.8	1.6	4.8	13.0

Continued

Table 5.—Continued

Seedlot number	Parentage ♀ ♂	Survival (%)	Height (ft)	Diameter (in)	Form[a]	Tallest tree (ft)
702	thunb × (densi × thunb)	15	14.7	1.7	4.3	19.0
707	thunb × (densi × thunb)	10	11.5	1.2	4.5	13.0
713	thunb × (densi × thunb)	40	13.7	2.1	4.9	21.0
730	thunb × (densi × thunb)	20	9.5	1.2	4.2	14.0
727	thunb × (densi × thunb)	20	18.2	2.3	4.2	21.0
719	thunb × (densi × thunb)	25	10.6	1.3	5.0	15.0
703	thunb × tab	70	20.6	3.6	3.8	24.0
706	thunb × tab	70	20.4	3.7	3.6	25.0
714	thunb × tab	90	22.3	3.8	3.7	30.0
718	thunb × tab	65	23.7	4.0	3.1	26.0
	GP-2C-56					
763	bank × OP	75	23.4	3.8	3.5	30.0
42-353-50	bank × OP	75	20.6	2.9	3.2	28.0
566	bank × (cont × bank)	75	26.2	4.8	3.1	30.0
762	bank × (cont × bank)	75	25.6	4.2	2.8	31.0
764	bank × (cont × bank)	90	23.7	4.1	3.6	29.0
	GP-2B-56					
754	nigra × OP	25	—	2.9	3.5	3.7[b]
N987	nigra × OP	25	—	2.1	3.2	3.0[b]
N978	densi × OP	60	—	3.6	3.4	4.4[b]
N980	densi × OP	55	—	3.3	4.6	5.0[b]
N1009	syl × OP	80	—	3.6	3.6	4.7[b]
N1010	syl × OP	95	—	5.0	3.7	6.0[b]
N1128	syl × OP	100	—	4.3	3.5	5.5[b]
N1200	syl × OP	100	—	4.7	4.0	6.5[b]

[a]1—best; 5—poorest.
[b]Largest diameter.

APPENDIX

List of scientific and common names of species included in this report[1]

Section *Strobus*	
Subsection *Cembrae*	
P. cembra L.	Swiss stone pine
P. koraiensis Sieb. & Zucc.	Korean pine
Subsection *Strobi*	
P. ayacahuite Ehrenberb	Mexican white pine
P. flexilis James	Limber pine
P. griffithii McClelland	Himalayan white pine
P. parviflora Sieb. & Zucc.	Japanese white pine
P. peuce Grisebach.	Balkan pine
P. strobus L.	Eastern white pine
Section *Pinus*	
Subsection *Pinus*	
P. densiflora Sieb. & Zucc.	Japanese red pine
P. massoniana Lamb.	Masson pine
P. nigra Arn.	Austrian pine
P. resinosa Ait.	Norway pine
P. sinensis[2]	
P. sylvestris L.	Scots pine
P. tabulaeformis Carr.	Chinese pine
P. taiwanensis Hayata	Formosa pine
P. thunbergiana Franco.	Japanese black pine
P. yunnanensis Franchet.	Yunnan pine
Subsection *Australes*	
P. echinata Mill.	Shortleaf pine
P. rigida Mill.	Pitch pine
Subsection *Contortae*	
P. banksiana Lamb.	Jack pine
P. contorta Dougl.	Lodgepole pine

[1]Critchfield and Little 1966.
[2]Variety of *P. yunnanensis*.

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DIAMETER GROWTH OF UPLAND OAKS AFTER THINNING

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Abstract

Diameter growth rates of the 40 largest trees per acre on 154 permanent plots in Kentucky, Ohio, Missouri, and Iowa were analyzed to determine the effects of thinning in upland oak stands. The plots were established over a wide range of stocking levels, stand age, and site conditions. Thinning resulted in increased diameter growth of the residual trees, regardless of age or site. The heavier the thinning, the greater the response. Diameter growth rates, and growth response after thinning relative to a control, were better in younger stands. Growth rates were higher on better sites, but the growth response relative to a control was not influenced much by site. In most instances the largest 40 trees per acre responded as well or better to thinning than the second 40 largest.

INTRODUCTION

THE MOST EXTENSIVE HARDWOOD timber type in the United States is the upland oak forest type—nearly 116 million acres, or about one-quarter of the commercial forest land is occupied by this forest type. A series of studies was begun in 1949 to estimate growth and yield from this timber type for a range of stocking levels. The studies were designed to help forest-land managers resolve the many questions about growth response in managed upland oak stands. An evaluation of these thinning studies is not complete without considering the sizes of the trees produced rather than only the volume they represent. The purpose of this paper is to determine the effects of thinning on the diameter growth rates of the residual trees.

The studies were established in different geographical areas, and the diameter growth rates reported in this paper cover a wide range of stocking levels, stand age, and site conditions. The results of thinning experiments over a narrower range of conditions have been reported for the upland oak type. Dale (1968) found that 25- to 33-year-old stands in Kentucky and Iowa responded well to thinning. Trees growing in heavily thinned areas grew almost twice as fast in diameter as those at maximum stocking, and those in medium-stocked areas grew 35 to 70 percent more. Minckler (1957) reported that pole-size white oak trees released from overhead shade grew 46 percent faster in diameter than the unreleased trees. The age of the trees, 35 to 100 years, did not influence the response to release. Formerly fast-growing trees showed no differences in diameter growth between sites, but formerly slow-growing trees grew 27 percent faster on better sites.

STUDY AREAS

Data from eight growth and yield studies from Kentucky, Ohio, Missouri, and Iowa were used to determine diameter growth rates (Fig. 1 and Table 1). There were 154 permanent plots in the analysis. The objectives, methods of treatment, and criteria for plot selection were about the same for all study areas.

All plots were initially located in fully stocked, even-aged upland oak stands that showed little evidence of recent logging or natural disturbances. Plot sizes ranged from 0.2 acre (0.081 ha) for study area 41 to 1.0 acre (0.405 ha) for study area 13.

Detailed measurements of at least 10 sample trees per plot provided age and site information. The site index for each plot was determined from Schnur's (1937) site index curves for upland oaks. The index ranged from an average of 59 for study area 41 to 73 for study areas 21 and 22. There was a wide range in stand age among the study areas—from age 24 in area 31 to age 80 in area 13.

Figure 1.—Location of the study plots.

Species composition of the largest trees varied mostly between states. The trees in the Kentucky study were primarily white oak; in Missouri, black oak; and in Ohio, a mixture of scarlet and black oak. The Iowa study area had 58 percent white oak and 38 percent black oak.

All plots were thinned in 1961 or 1962 except those in study area 13, which were thinned in 1959. Plots in area 41 were first thinned in 1949, but received a second thinning in 1961. The thinning method is best described as "free"—the marker was free to remove trees from all crown classes. The objective was to leave a suitable number of the best trees as evenly spaced as possible throughout the plot. An isolation strip around each plot was also thinned.

The degree of thinning was controlled by reducing the basal area or the stocking level (Gingrich 1967) to the desired percentage. Cutting varied from very light or none to 70 or 80 percent of the original basal area (Figs. 2a through 2c).

Table 1.—Characteristics of study areas used to analyze diameter growth rates of 40 largest trees per acre

Study	Location	No. of plots	Plot size (acres)	Date thinned	Initial average age (years)	Average site index	Growth period analyzed	Species composition of 40 largest trees per acre		
								White oak	Black and scarlet oak	Other
								Percent		
11	Kentucky	23	.5	1961	34	70	1962-1968	73	23	4
			.25	1962						
13	Kentucky	12	1.0	1959	80	64	1962-1968	89	5	6
21	Ohio	16	.5	1961	33	73	1962-1968	9	84	7
22	Ohio	6	.25	1961	51	73	1963-1968	3	97	0
24	Ohio	15	.5	1961	61	64	1962-1968	25	75	0
31	Missouri	24	.5	1962	24	71	1962-1967	2	98	0
		10	.5	1962	25	63	1962-1967	4	96	0
32	Missouri	14	.5	1961	43	70	1961-1967	5	94	1
		14	.5	1961	40	61	1961-1967	3	96	1
41	Iowa	20	.2	1961[a]	37	59	1961-1968	58	38	4

[a]This was the second thinning for study area 41. The first thinning was made in 1949 at age 25.

Figure 2a.—Plot 9 on Kentucky study 11, age 33. Stocking was reduced to 37.13 percent.

ure 2b.—Plot 9 on Ohio study 24, age 55. Un-nned plot was 94.22 percent stocked.

Figure 2c.—Plot 1 on Kentucky study 13, age 81. Thinned to 58.36 percent stocking.

METHODS

The differences in diameter growth rates of thinned and unthinned stands are often tested by comparing the diameters of the trees of average basal area (quadratic mean dbh). This method is appropriate if the comparisons are made between the average diameter of *equal* numbers of crop trees per acre (Adams and Chapman 1942; Smith 1962). If the numbers of trees are not equal, there may be serious distortions in the comparisons. For this reason I have used the equivalent of the 40 largest surviving trees per acre from each plot for comparisons. The 40 largest trees per acre is commensurate with the European standard of 100 trees per ha. The development of these larger trees is important because they will most likely constitute a large portion of the final harvest volume.

A total of 5,880 trees from the 154 plots were used to determine diameter growth rates. The number of trees in each plot used in the analysis depended on the plot size. For example, for a 1.0-acre plot, it was the 40 largest trees; for a 0.2-acre plot, only the 8 largest trees.

Measurements were not taken in all study areas at the same time. Those measurements taken near the time of the 1962-1968 period were used in the analysis. A measurement period common to all the areas is desirable so that effects of weather can be minimized in the analysis. Data for a 6-year growth period were available for most areas, but only a 5-year period for three areas, and a 7-year period for the Iowa area (Table 1).

The trees in the Kentucky and Ohio plots were remeasured as recently as 1977. Although it would be desirable to study diameter growth over a longer period, the difference in thinning schedules for the various studies precluded the use of the additional data.

For analysis, the experimental plots were categorized by percent stocking. Only those trees $\geq$2.6 inches in diameter at breast height (dbh) were used in calculating plot stocking. I used percent stocking because it expresses the same relative degree of site occupancy, regardless of age or site. Stocking categories used were 0-31, 32-45, 46-55, 66-80, and 80+ percent. These levels resulted in a balanced distribution of plots among stocking levels within a study area. Though there were light thinnings on some of the plots at the very high stocking level, these plots approach normal conditions and serve as controls.

Diameter growth rates were also categorized by site index. Site index 65 was arbitrarily selected as the dividing line between poor-medium and medium-good sites. The objective for a given study was to establish all plots on similar sites. Therefore, the average site index for the study area is the site index category. This average reflects the general situation on the ground, but a few plots on a given area may have had a site index greater than 65 while the remainder had a site index less than 65, or vice versa. Sample plots on the Missouri study areas were deliberately established on both good and poor sites, and the data were categorized accordingly.

There was no breakdown of data by species. Species composition was consistently one major oak species within a study area (Table 1).

RESULTS

The periodic annual diameter growth rates are shown in Tables 2a and 2b for each of the eight studies. The breakdown of the data into age $\times$ stocking $\times$ site categories resulted in a considerable number of empty cells. Therefore, no statistical analyses were performed. However, the actual diameter growth rates for this wide range of stocking levels, stand age, and site index provide meaningful information about the factors that influence diameter growth in managed stands of upland oaks.

Stocking. The effects of stocking on diameter growth should be judged from the growth rates within a given age (study area) and site category. Direct comparisons between stocking levels within an area should be made with caution because of unequal sample sizes. For example, the diameter growth on the poor-medium site on study 32 increased by 100 percent from 0.13 inch on the very high stocking level to 0.26 inch on the very low stocking level (Table 2b). However, six plots were

Table 2a.—Periodic annual diameter growth rates of 40 largest and second 40 largest trees per acre, average site index >65, by stocking level

Percent stocking	N[a]	Avg. basal area (ft^2/acre)	Avg. s.p.[b]	Initial avg. dbh[c]		Periodic annual dbh growth	
				40 largest trees	Second 40 trees	40 largest trees	Second 40 trees
				inches			
			STUDY 31, MISSOURI (24 plots, avg. age 23.5)				
Very low (0-31)	160	24.68	29.39	6.08	4.98	0.34	0.31
Low (32-45)	20	32.11	43.67	5.26	4.34	0.26	0.24
Medium (46-65)	180	40.58	48.45	6.24	5.12	0.27	0.23
High (66-80)	100	59.93	72.22	6.69	5.75	0.23	0.20
Very high (80+)	20	63.37	80.97	6.13	5.31	0.19	0.17
			STUDY 21, OHIO (16 plots, avg. age 32.5)				
Very low (0-31)	—	—	—	—	—	—	—
Low (32-45)	80	39.74	41.82	7.86	6.36	0.21	0.17
Medium (46-65)	160	51.45	56.40	7.86	6.48	0.15	0.13
High (66-80)	60	66.47	74.01	7.95	6.68	0.16	0.12
Very high (80+)	20	79.95	89.83	8.41	7.12	0.15	0.13
			STUDY 11, KENTUCKY (23 plots, avg. age 34.0)				
Very low (0-31)	70	18.82	21.98	6.01	4.91	0.32	0.29
Low (32-45)	130	31.74	37.90	6.29	5.27	0.25	0.24
Medium (46-65)	60	47.52	56.29	6.70	5.74	0.25	0.19
High (66-80)	80	64.24	77.37	7.21	5.68	0.20	0.17
Very high (80+)	40	71.21	87.67	7.16	5.79	0.21	0.17

Continued

Table 2a.—Continued

Percent stocking	N[a]	Avg. basal area (ft^2/acre)	Avg. s.p.[b]	Initial avg. dbh[c]		Periodic annual/ dbh growth	
				40 largest trees	Second 40 trees	40 largest trees	Second 40 trees
				inches			
			STUDY 32, MISSOURI (14 plots, avg. age 43.4)				
Very low (0-31)	—	—	—	—	—	—	—
Low (32-45)	—	—	—	—	—	—	—
Medium (46-65)	140	53.12	50.07	9.92	8.24	0.17	0.16
High (66-80)	100	69.65	67.69	9.98	8.36	0.16	0.13
Very high (80+)	40	89.61	86.62	11.10	8.94	0.14	0.12
			STUDY 22, OHIO (6 plots, avg. age 51.2)				
Very low (0-31)	—	—	—	—	—	—	—
Low (32-45)	—	—	—	—	—	—	—
Medium (46-65)	60	68.94	63.86	10.73	8.80	0.16	0.13
High (66-80)	—	—	—	—	—	—	—
Very high (80+)	—	—	—	—	—	—	—

[a]Number of 40 largest trees per acre used to compute growth rates.
[b]Initial average stocking percent (s.p.).
[c]Diameter in cm = 2.54 × diameter in inches.

Table 2b.—Periodic annual diameter growth rates of 40 largest and second 40 largest trees per acre, average site index ≤65, by stocking level

Percent stocking	N[a]	Avg. basal area (ft^2/acre)	Avg. s.p.[b]	Initial avg. dbh[c]		Periodic annual dbh growth	
				40 largest trees	Second 40 trees	40 largest trees	Second 40 trees
				inches			
			STUDY 31, MISSOURI (10 plots, avg. age 24.8)				
Very low (0-31)	80	21.50	27.50	5.42	4.34	0.25	0.18
Low (32-45)	—	—	—	—	—	—	—
Medium (46-65)	120	38.11	50.47	5.29	4.66	0.20	0.18
High (66-80)	—	—	—	—	—	—	—
Very high (80+)	—	—	—	—	—	—	—
			STUDY 41, IOWA (20 plots, avg. age 37.0)				
Very low (0-31)	—	—	—	—	—	—	—
Low (32-45)	16	38.06	36.54	8.38	7.44	0.26	0.21
Medium (46-65)	40	53.58	53.42	8.99	7.52	0.20	0.17
High (66-80)	40	70.53	70.83	9.02	7.68	0.18	0.17
Very high (80+)	64	85.48	91.10	8.61	7.18	0.16	0.15
			STUDY 32, MISSOURI (14 plots, avg. age 40.4)				
Very low (0-31)	120	30.00	29.67	8.28	6.94	0.26	0.23
Low (32-45)	—	—	—	—	—	—	—
Medium (46-65)	100	50.19	48.68	9.26	7.76	0.18	0.16
High (66-80)	40	69.87	71.43	9.17	7.57	0.15	0.13
Very high (80+)	20	85.19	88.14	9.08	7.62	0.13	0.11

Continued

Table 2b.—Continued

Percent stocking	N[a]	Avg. basal area (ft^2/acre)	Avg. s.p.[b]	Initial avg. dbh[c]		Periodic annual/ dbh growth	
				40 largest trees	Second 40 trees	40 largest trees	Second 40 trees
				inches			
			STUDY 24, OHIO (15 plots, avg. age 61.2)				
Very low (0-31)	—	—	—	—	—	—	—
Low (32-45)	80	47.66	42.21	11.26	8.50	0.15	0.11
Medium (46-65)	140	60.81	54.34	11.41	9.09	0.12	0.10
High (66-80)	60	80.22	71.43	11.69	9.55	0.11	0.09
Very high (80+)	20	100.42	94.22	11.16	9.37	0.11	0.09
			STUDY 13, KENTUCKY (12 plots, avg. age 80.0)				
Very low (0-31)	—	—	—	—	—	—	—
Low (32-45)	160	45.18	40.38	11.54	7.65	0.17	0.14
Medium (46-65)	160	62.09	55.71	12.18	9.00	0.14	0.11
High (66-80)	160	79.07	69.80	12.98	9.91	0.15	0.11
Very high (80+)	—	—	—	—	—	—	—

[a]Number of 40 largest trees per acre used to compute growth rates.
[b]Initial average stocking percent (s.p.).
[c]Diameter in cm = 2.54 × diameter in inches.

used to determine the average at the very low stocking level, but only one plot was used to determine the average at the very high stocking level. One plot does not provide sufficient information to make concrete conclusions. We should look more for general trends in the data in Tables 2a and 2b, as opposed to specific comparisons

Diameter growth at the very low stocking levels (0 to 31 percent) was considerably greater than at the higher stocking levels. The 0.34-inch annual increment at this very low stocking level on study area 31 (Table 2a) approaches the maximum diameter growth that we can expect in upland oak stands. This area was in a young black oak stand growing on a good site. However, such a severe thinning is not a common practice in the field and is not recommended. This stocking level closely resembles a seed-tree cutting, and the volume growth per acre is greatly reduced.

Accelerated growth was maintained at the low stocking levels (32 to 45 percent), but dropped some from the very low. Again, this stocking level represents a severe thinning not commonly practiced, and it is not recommended.

The diameter growth rates at the medium stocking levels (46 to 65 percent) are most informative. In practice, most medium to heavy thinnings today result in this stocking level. There was some increase in the diameter growth on all study areas except study 21, but no sensational differences from the diameter growth on the very highly stocked plots. We probably cannot expect more than a 0.03- to 0.05-inch increase in annual increment at this medium stocking level. This response is somewhat below what many foresters would anticipate but, on the average, it represents about a 20 percent increase over unthinned stands.

Growth rates at the high stocking levels (66 to 80 percent) showed only a slight increase in relation to the very highly stocked plots. Many light to medium thinnings in the field result in this level of stocking. Only about a 0.01- to 0.02-inch increase in diameter growth can be expected at this stocking level, which is about a 10 percent increase on the average.

Age. The general trends in the data indicate a growth response after thinning, regardless of age. However, the response relative to a control was somewhat greater in the younger stands than in the older. In other words, there was some interaction between age and stocking.

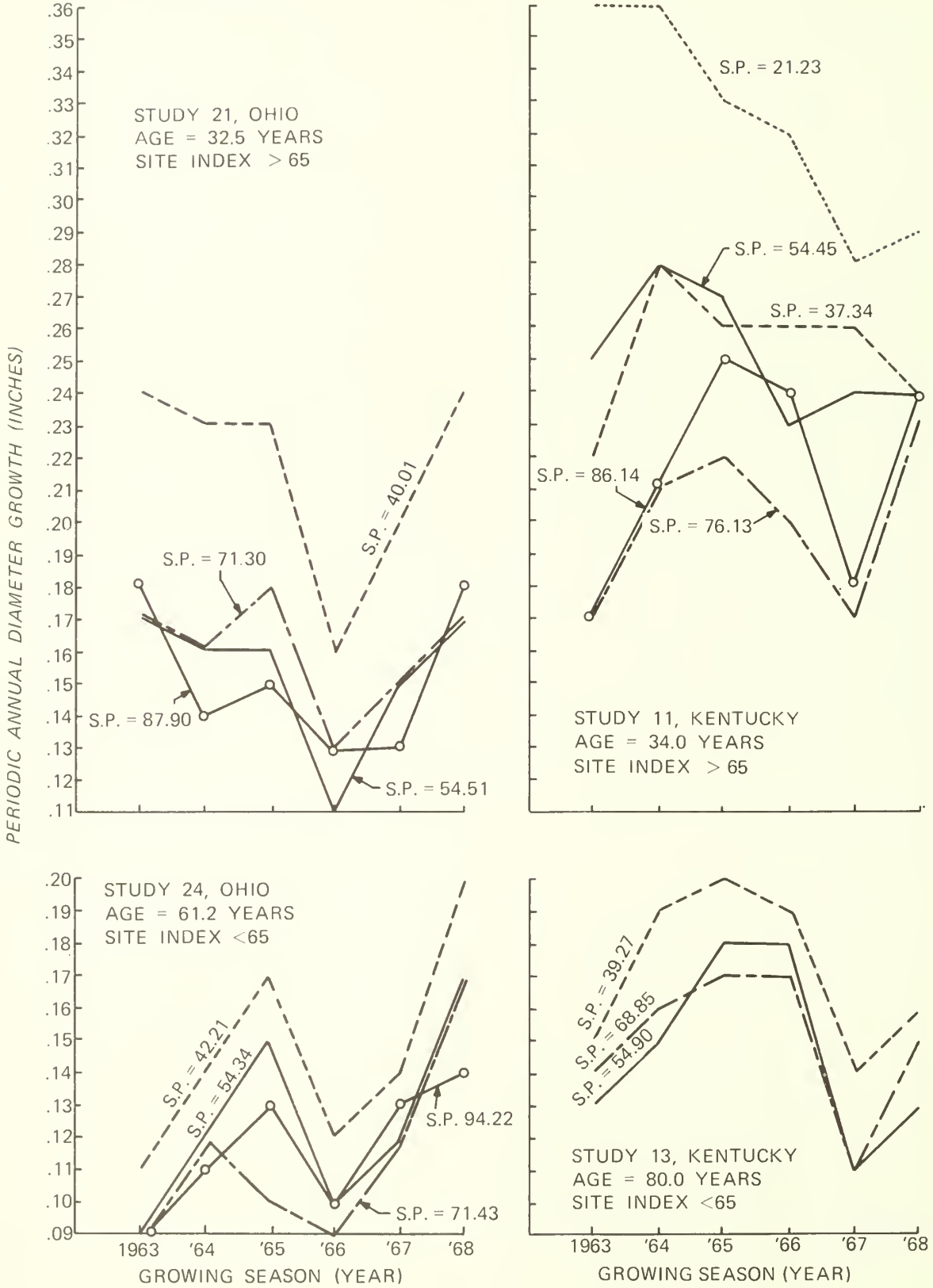
The absolute age effect on diameter growth is also reflected in the data. It is, however, combined with species effects and geographic location (mostly weather) for the different growth and yield studies. The general trend indicates a decrease in diameter growth with increasing age. This result was expected because the older trees were much larger. Studies 24 and 21 in Tables 2a and 2b seem "out of place" in the progression of ages because their growth rates were so small. Consistently poor weather such as drought and late frost over the growth period caused this reduction in diameter growth.

Site. A definite response to thinning regardless of site is reflected by the data in Tables 2a and 2b. Studies 31 and 32 provide the best information on site effects on diameter growth because the sample plots in these two areas were deliberately established on good and poor sites. Comparison between other study areas of similar ages should be made with caution because the site effects are confounded with species effects and geographic location (weather).

The results suggest that site does not have much, if any, effect on the diameter growth response after thinning, relative to a control. Diameter growth on study area 32 averaged 0.03 inch (0.08 cm) greater on the medium stocking level than on the very high stocking level on the good sites, but 0.05 inch (0.13 cm) greater on the poorer sites.

The absolute site effect on diameter growth is also reflected in the data. Diameter growth of the 25-year-old stand in study 31 averaged 0.09 inch (0.23 cm) more on the good sites for the very low stocking level, and 0.07 inch (0.18 cm) more for the medium stocking level (Tables 2a and 2b). The diameter growth of the 40-year-old stand in study 32 was slightly better on the good site for the high and very high stocking levels only.

Figure 3.—Periodic annual diameter growth rates of 40 largest trees per acre, 1962-1968 (s.p. = stocking percent).



Largest 40 trees per acre vs. second 40 largest. Which trees respond most to thinning is of major importance. Is the growth response greater in the larger future crop trees, or is the response primarily in the smaller future crop trees? To answer this question I calculated the diameter growth rates for the second 40 largest trees per acre (Tables 2a and 2b). The results indicate that in most cases the growth response relative to a control was as much or more for the largest 40 trees per acre than it was for the second 40 largest. The absolute diameter growth, as expected, was always greater for the largest 40 trees per acre. These trends were consistent for all age and site categories.

Growth trends. Diameters were measured annually from 1962 to 1968 on four study areas. The six periodic annual diameter growth rates for each study are plotted by stocking level in Figure 3. Tracing growth rates over time is an attempt to determine how long the response to thinning is sustained.

The fact that the diameter growth for most stocking levels within a study area increased and decreased at similar times indicates that weather had a major effect on the growth of the residual trees. Growth was very poor during 1966 in Ohio and 1967 in Kentucky. It decreased as much as 0.07 inch (0.18 cm) during those years in study areas 21 and 13.

The low stocked plots (31 to 45 percent) had consistently higher growth rates than the other stocking levels in studies 21, 24, and 13. The growth response at this stocking level was apparently maintained for at least the six growing seasons used in the analysis.

The growth rate at the very low stocking level in study 11 was very high for the first two growing seasons, but then declined relative to the other stocking levels. This indicates that the very high growth rate after a severe thinning may be short lived.

Other than the effects of weather on growth, no discernible trends in growth rate are apparent for the other stocking levels. The growth rates for the medium stocking levels even dropped below those for the highly stocked plots in several instances.

SUMMARY

The thinning studies in this analysis cover a wide range of stocking levels, stand age, and site conditions. The variability in responses to thinning was apparent even for this large data set. General trends in the data indicate that the diameter growth of the largest 40 trees per acre showed a distinct response to thinning, regardless of age or site. The heavier the thinning, the greater the response. Diameter growth rates, and growth response after thinning relative to a control, were better in younger stands. Growth rates were higher on better sites, but the growth response relative to a control was not influenced much by site. In most instances the largest 40 trees per acre responded as well or better to thinning than the second 40 largest.

The diameter growth response of upland oaks after thinning is consistent with the response of faster growing species such as ponderosa pine, Douglas-fir, western hemlock, and Sitka spruce (Barrett 1969; Reukema 1972; Hilt 1977; Farr and Harris 1971).

The diameter growth rates at the medium stocking levels for the largest 40 trees per acre were generally 0.03 to 0.05 inch better (approximately 20 percent) than those of very highly stocked plots. If this kind of response can be maintained through repeated thinnings, foresters should be able to lower the current rotation age of 100 years to about 80 years for sawlog management in upland oak stands. Or, if the rotation age is kept at 100 years, there should be considerably more veneer-size logs at the time of harvest. Information on the growth responses after repeated thinnings in upland oak stands will be available soon, as many of the plots used in this analysis have now been thinned two or three times.

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OLEORESIN CRYSTALLIZATION IN EASTERN WHITE PINE:

Relationships with Chemical Components of Cortical Oleoresin and Resistance to the White-Pine Weevil

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OLEORESIN CRYSTALLIZATION IN EASTERN WHITE PINE:

Relationships with Chemical Components of Cortical Oleoresin and Resistance to the White-Pine Weevil

Abstract

Natural and weevil-larva-induced crystallization of oleoresin from 45 eastern white pine trees with known resin acid and monoterpene composition, and from 59 pairs of nonweeviled and heavily weeviled trees from the same seed sources, was examined in mid- and late spring. Very little difference was found between larva-induced and natural crystallization. Strobic acid—usually the major resin acid found in the cortical oleoresin of eastern white pine—was positively correlated with the rate and extent of crystallization. Crystallization of oleoresin from the same trees varied greatly between sampling dates, but oleoresin from white pines with concentrations of strobic acid of less than 5 percent did not crystallize even after 3 to 10 days from the time of collection. Trees with high concentrations of strobic acid had oleoresin that crystallized within 4 hours. Concentration of sandaracopimaric acid was also positively correlated with crystallization. Concentrations of abietic and neoabietic acids, when expressed as proportions of the total resin acids, were negatively correlated with crystallization. None of eight monoterpenes was consistently related to crystallization properties.

Variation in crystallization reactions is not useful as a selection criterion for weevil resistance. Although noncrystallizing oleoresin was found more frequently among heavily weeviled trees than in nonweeviled trees, the differences were small and not significant. Eastern white pine trees with oleoresin that does not crystallize are rare. Only eight trees had oleoresin that did not crystallize after 3 to 10 days from both sampling dates, and of these, six had been heavily weeviled. Most potential candidates for resistance breeding programs would not be selected because 58 percent of the trees that had resisted weevil attack had oleoresin that crystallized after 4 hours and 97 percent had oleoresin that crystallized after 3 days.

INTRODUCTION

FOR MANY YEARS, researchers attempting to breed eastern white pine trees (*Pinus strobus* L.) that are resistant to the white-pine weevil (*Pissodes strobi* Peck) have been searching for host characteristics, both morphological and biochemical, that are responsible for or correlated with resistance and could be used in an indirect selection program. As early as 1965, Santamour suggested that noncrystallization of cortical oleoresins of white pines may be correlated with resistance to attack by the white-pine weevil; a finding later substantiated by van Buijtenen and Santamour (1972).

Recently, Santamour and Zinkel (1976, 1977) have proposed an interesting hypothesis linking low concentrations or absence of strobic acid—one of the major resin acids found in the cortical oleoresin of eastern white pine—to noncrystallization of oleoresin, and consequently, to resistance to the white-pine weevil. They have advocated screening populations and provenances of eastern white pine to find prospective parents with no strobic acid for use in a program to breed weevil-resistant trees.

Santamour and Zinkel's proposal was greeted with enthusiasm by those concerned with the white-pine weevil problem, but in a recent study I have found that eastern white pines with no strobic acid are as susceptible to white-pine weevil attack as trees with high concentrations (Wilkinson 1979).

Apparently, the three-way relationship involving strobic acid content, oleoresin crystallization, and weevil resistance is still open to question. In this study the relationships between oleoresin crystallization with concentrations of cortical resin acids and monoterpenes and the occurrence of weeviling in eastern white pine have been reexamined.

MATERIALS AND METHODS

The trees usd for this study are all growing in three geographic seed source tests planted in 1960 on the Massabesic Experimental Forest, Alfred, Maine—Plantations 1, 2, and 3. The plantations contain 24 to 28 geographic seed sources of eastern white pine originating from throughout the species range. Each seed source is represented in Plantation 1 by one-tree plots and in Plantation 2 by two-tree plots located in 24 randomized blocks. Plantation 3 has four-tree plots in 12 blocks. The trees were all 22 years old when the study was conducted.

All three plantations are adjacent and there is a high weevil population in the immediate area. Initially all three plantations were protected from the white-pine weevil with insecticide. This was discontinued in 1967 for Plantation 1 and in 1972 for Plantations 2 and 3. Each tree in each plantation was evaluated for weevil damage; Plantation 1 initially in 1970 and again in 1976, and Plantations 2 and 3 in 1976. In each case each tree was rated as heavily, lightly, or not weeviled. Heavily weeviled was defined as having leader mortality in more than two years; lightly weeviled as having leader mortality in 1 or 2 years; and non-weeviled as being free of attack or leader damage in at least 3 years.

Natural crystallization of oleoresin was tested in mid-May and late June, 1978. During the June test larva-induced crystallization was examined using both weevil larvae reared on white pine stems in the laboratory and ones collected from naturally infested stems. Crushed white-pine weevil larva heads and other parts are reported to induce crystallization in white pine cortical oleoresin (Santamour 1965).

The procedure for analyzing oleoresin crystallization largely followed that described by Santamour (1965) and van Buijtenen and Santamour (1972). The experimental procedure was as follows: Lateral branches were cut from near the top of the crown of each tree and transported to a laboratory. Small incisions were then made into the cortex of 1-year-old internodes of each branch and two 10-microliter samples of the exuded oleoresin were drawn into calibrated microcapillary tubes and then transferred to glass microscope slides. In June, a third oleoresin sample was collected from each tree and a weevil larva head was crushed into that oleoresin droplet.

Crystallization of the oleoresins at 21° to 27°C was observed and scored by observation of the droplets through a binocular dissecting scope at 4 hours, 8 hours, 24 hours, and at irregular intervals for 3 to 10 days after collection; at which time crystallization remained unchanged for all trees. Each oleoresin sample was scored on a numerical scale based on the area crystallized at each time period. The scoring system was the same as that used by van Buijtenen and Santamour (1972):

0 No crystals
1 Few crystals
2 ¼ crystallized
3 ½ crystallized
4 ¾ crystallized
5 Crystallization complete

Oleoresin crystallization properties in eastern white pine were examined in two concurrent studies.

Study 1: Resin acid concentration and crystallization

The cortical resin acids of 88 trees from Plantation 1 were quantitatively analyzed by gas-liquid chromatography in 1977 (Wilkinson 1979). The monoterpene composition of the cortical oleoresin of these same trees had been determined previously (Bridgen et al. In press). The 88-tree sample consisted of 48 non-weeviled trees and 40 heavily weeviled trees. Strobic acid concentration in these trees ranged from 0.0 to 34.5 percent of the resin acids. Crystallization was studied in the 10 trees with the highest and the 10 trees with the lowest concentrations of strobic acid, plus 1 of each 3 trees from among those with intermediate amounts for a total of 45 trees.

Simple correlations between crystallization scores at each observation period and concentrations of all resin acid and monoterpene components were calculated. Crystallization scores in May and June were treated separately as they were quite variable within the same trees. Replicate samples within a collection period, May or June, had identical or similar scores; and means of the two replications were

used for calculating correlations. Larva-induced crystallization scores were similar to scores obtained for natural crystallization, and with only one exception, correlations with resin acid and monoterpene components were nearly identical to those obtained with natural crystallization. Addition of crushed adult weevil heads and heads of horsefly larvae to several additional oleoresin samples resulted in crystallization reactions identical to natural crystallization. Therefore, all correlations reported here are for natural oleoresin crystallization.

Study 2: Crystallization and weevil resistance

Crystallization was studied in nonweeviled trees that exceeded the plantation mean in height and diameter in each of the three plantations, and in a corresponding heavily weeviled tree from the same seed source. Only fast-growing nonweeviled trees were used to reduce the chance that selected trees had escaped weevil attack because of low vigor. In Plantation 1 there were 15 nonweeviled trees that exceeded the mean growth rate at 10 years; 2 years before the first weevil attack. In Plantations 2 and 3 there were 24 and 20 trees, respectively, that exceeded their mean plantation growth rate at 17 years; 1 year after first exposure to weevil attack. In all, crystallization was studied in 59 nonweeviled and 59 heavily weeviled trees for a total of 118.

Seed-source pairs of crystallization scores for nonweeviled and heavily weeviled trees were compared. A sign test was made to determine statistical significance. Crystallization differences between nonweeviled and heavily weeviled trees were also tested by 2 × 5 contingency tables and chi-square test for independence with 4 degrees of freedom. A further test was made by categorizing each tree as having noncrystallizing (score 0) or crystallizing (score 1-5) oleoresin and using a 2 × 2 table with 1 degree of freedom. Comparisons were made for each observation period: 4, 8, and 24 hours and 3 to 10 days; for each sampling period, May and June; and for each plantation separately and all three plantations combined. A series of analyses of variance was also used to test for seed source differences in oleoresin crystallization.

RESULTS AND DISCUSSION

The hypothesis attributing noncrystallization of oleoresin to the absence of strobic acid in eastern white pine had not, until this time, been extensively tested. Studies of oleoresin crystallization reactions, coupled with quantitative gas-chromatographic analyses of resin acids, have involved only a relatively few white pines and white pine hybrids. On the other hand, the reported relationship between noncrystallization of oleoresin and weevil resistance has generally been accepted without question. Surprisingly, this study reveals that there is a clear relationship between crystallization and strobic acid, but that there is no relationship between crystallization and weevil resistance or susceptibility.

Study I: Strobic acid concentration and crystallization

The rate and extent of oleoresin crystallization varied considerably from one tree to another. Oleoresin from white pines with little or no strobic acid did not crystallize readily, even after several days (Table 1). Only 1 tree among 10 with low concentrations of strobic acid had oleoresin that was half crystallized after 3 to 10 days, and this tree had the highest concentration of strobic acid within the group. Oleoresin from four trees with less than 5 percent strobic acid did not crystallize naturally in May or in June; nor did oleoresin from these trees crystallize in the presence of weevil larva heads.

Trees with high concentrations of strobic acid had oleoresin that was half crystallized after 8 hours, and all 10 trees had some crystals forming in the oleoresin after only 4 hours. In May, two trees with 32.8 and 34.5 percent strobic acid had oleoresin that was completely crystallized after 4 hours, although crystallization was slower in these same trees in June.

Resin crystallization is probably dependent on specific resin acids rather than on total resin acid content of the oleoresin (Santamour 1967). It has generally been suggested that any resin acid present in the oleoresin at concentrations greater than 30 percent can trigger the crystallization reaction. Interestingly enough, of the four trees that had low concen-

Table 1.—Mean oleoresin crystallization scores (May and June) in 10 eastern white pine with the lowest and the 10 with the highest strobic acid concentrations

Strobic acid concentration (Percent of resin acids)	Crystallization score after			
	4 hours	8 hours	24 hours	3-10 days
0.0	0	0	0	0
0.0	0	0	0	0
3.1	0	0	0	0
4.1	0	0	0	0
10.1	0	0	1	1
11.6	0	0	0	1
13.0	0	1	1	2
13.0	0	0	1	1
13.5	0	0	1	1
13.5	0	1	2	3
28.8	1	2	2	3
29.0	1	3	3	5
29.0	1	2	3	4
29.2	1	1	2	3
29.5	3	3	4	5
29.8	1	1	1	3
31.4	1	3	3	5
32.8	3	3	3	4
33.3	1	2	3	5
34.5	3	3	3	4

trations of strobic acid and oleoresin that did not crystallize, two had concentrations of neoabietic acid greater than 30 percent and the other two had more than 27 percent.

Oleoresin crystallization differed between the two sampling dates in May and June as well as between individual trees. Twenty-five of 140 trees from both studies had oleoresin that crystallized readily at one sampling time but did not crystallize at all at the other. Correlations between crystallization scores in May and June were only .188 at 4 hours, .262 at 8 hours, .239 at 24 hours, and .393 at 3 to 10 days.

Correlations between strobic acid concentration and crystallization were highly significant for both sampling dates (Table 2). Oleoresin with either high or low concentrations of strobic acid crystallized rapidly or not at all in both May and June, accounting for the similarity in correlation coefficients for the two dates.

Somewhat surprisingly, three other resin acids are also significantly correlated with crystallization; and the coefficients are as large as, or larger than, those for strobic acid. Like strobic acid, sandaracopimaric acid is positively correlated with crystallization. Abietic acid and neoabietic acid are both negatively correlated with crystallization. Correlation coefficients were generally progressively higher from 4 hours to 3 to 10 days for all four resin acids that are significantly correlated with crystallization. But all four resin acids were significantly correlated with crystallization scores after only 4 hours.

The correlations between sandaracopimaric, abietic, and neoabietic acids and crystallization may simply be due to correlations between these resin acids and strobic acid. However, only two trees with intermediate amounts of strobic acid (20 percent) had oleoresin that crystallized readily after only 4 hours. These two trees had the lowest abietic acid (7.2 per-

Table 2.—Simple correlations (r) between oleoresin crystallization and relative concentration of cortical oleoresin components in eastern white pine

Oleoresin components	May sample				June sample			
	Crystallization after:				Crystallization after:			
	4 hr	8 hr	24 hr	3-10 days	4 hr	8 hr	24 hr	3-10 days
Resin acids								
Sandaracopimaric	0.393**	0.408**	0.495**	0.527**	0.372**	0.401**	0.437**	0.601**
Communic	−.134	−.151	−.097	−.081	.095	.150	.156	−.054
Levopimaric/palustric	.053	.027	−.121	−.168	−.126	−.112	−.133	−.282
Isopimaric	−.337*	−.255	−.116	−.075	−.060	−.041	−.029	−.119
Strobic	.425**	.491**	.564**	.599**	.424**	.462**	.487**	.663**
Dehydroabietic	−.184	.038	−.064	−.037	−.058	−.023	−.024	−.061
Abietic	−.466**	−.610**	−.678**	−.674**	−.413**	−.454**	−.498**	−.575**
Neoabietic	−.357*	−.376**	−.406**	−.451**	−.447**	−.465**	−.507**	−.567**
Monoterpenes								
Alpha-pinene	−.076	−.196	−.196	−.193	−.011	.024	.018	.064
Camphene	−.215	−.438**	−.388**	−.358*	−.040	.037	.029	−.034
Beta-pinene	.052	−.100	−.084	−.209	−.165	−.284	−.274	−.210
3-carene	.043	.193	.122	.234	.112	.170	.101	.132
Myrcene	.057	.036	.020	−.059	−.024	−.077	.049	−.102
Limonene	.008	.058	.117	.083	−.092	−.033	.002	−.055
Beta-phellandrene	−.161	.040	.056	.134	.240	.243	.196	.162
Terpinolene	.056	.176	.127	.248	.184	.199	.154	.157
Total monoterpene	−.006	.009	−.049	−.044	.002	.021	−.045	.012

*Significantly different at the .05 level of probability.
**Significantly different at the .01 level of probability.

cent) of any of the 45 trees examined. It may be that crystallization of oleoresin is retarded by high concentrations of some resin acids. Santamour (1967) has cited several instances where this proved to be true.

Only one monoterpene component of the oleoresin was significantly correlated with natural crystallization, and that correlation was not consistent. Camphene was significantly negatively correlated with crystallization in May but not in June. In May, oleoresin crystallization was negatively correlated, although not quite significantly, with oleoresin viscosity. Oleoresin droplets that tended to spread out on the glass slides crystallized more readily than those that remained as small-diameter droplets. Camphene was positively correlated with viscosity in these same trees (Bridgen et al. In press). In June, differences in viscosity, determined by measuring the diameter of oleoresin droplets, between trees were noticeably less pronounced than they were in May. Most samples were less viscous in June, possibly because of higher ambient temperatures at the time of collection.

Monoterpene concentrations in the oleoresin (including that of limonene, the only monoterpene related to weevil resistance by Bridgen et al.) is probably not directly related to crystallization. However, concentration of beta-phellandrene was significantly positively correlated with crystallization when crushed weevil larva heads were introduced into oleoresin samples. All other correlations between larva-induced crystallization and chemical components were nearly identical to those obtained with natural crystallization, and for that reason I did not report them here. Close inspection of oleoresin samples with introduced larva heads revealed that in trees with high beta-phellandrene a cloudy white precipitate could possibly be mistaken for crystallization. This precipitate was most noticeable at 4 hours, but tended to be obscured by normal crystallization as time passed. In fact, correlations between beta-phellandrene and crystallization were highest at 4 hours and were nonsignificant at 3 to 10 days. The precipitate was not found when natural crystallization was observed in trees with high concentrations of beta-phellandrene.

Table 3.—Simple correlations (r) between oleoresin crystallization and resin acid composition as a percentage of the oleoresin in eastern white pine

Resin acids	May sample				June sample			
	Crystallization after:				Crystallization after:			
	4 hr	8 hr	24 hr	3-10 days	4 hr	8 hr	24 hr	3-10 days
Sandaracopimaric	0.337*	0.399**	0.417**	0.449**	0.475**	0.494**	0.527**	0.644**
Communic	−.059	.042	.038	.085	.325*	.399**	.427**	.282
Levopimaric/palustric	.106	.184	.043	.027	.203	.146	.175	.077
Isopimaric	−.206	−.036	.020	.084	.217	.258	.280	.222
Strobic	.367*	.462**	.480**	.509**	.518**	.535**	.558**	.676**
Dehydroabietic	−.158	−.033	−.042	−.014	.002	−.058	−.050	−.138
Abietic	−.403**	−.449**	−.545**	−.514**	−.178	−.199	−.220	−.226
Neoabietic	−.210	−.080	−.156	−.142	.009	.021	.009	−.008
Total resin acids	.041	.167	.111	.146	.378**	.385**	.396**	.380**

*Significantly different at the .05 level of probability.
**Significantly different at the .01 level of probability.

In all, four resin acids were significantly correlated with crystallization scores in both May and June. The correlations in Table 2 are based on resin acid concentrations expressed as a percentage of the total resin acids (relative basis) and correlations due to constraint are present. Correlations in Table 3 are based on resin acid concentrations expressed as a percentage of the oleoresin volume analyzed. Correlations between crystallization and neoabietic acid concentration on an absolute volume basis are close to zero. The correlations between abietic acid and crystallization are also much lower than they are on a relative basis; in fact, they are nonsignificant in the June tests. A significant positive correlation between crystallization and communic acid was revealed by expressing resin acid concentration on an absolute basis, but only in the June tests. The positive correlations between crystallization and sandaracopimaric acid, and most importantly strobic acid, are consistently high regardless of how the data are expressed. Apparently the oleoresin crystallization reaction involves complex interactions between several resin acids. Multiple correlation analyses might have been useful to sort out these relationships, but were beyond the scope of this study.

My study confirms a strong relationship between strobic acid concentrations and crystallization of cortical oleoresin from eastern white pine. Concentration of strobic acid could be useful for predicting crystallization. If trees were located that have less than 5 percent strobic acid in their oleoresin, it would be fairly certain that oleoresin from those trees would not crystallize. But several trees with intermediate and even relatively high concentrations of strobic acid had oleoresin that crystallized in May but did not crystallize in June. The reverse pattern also occurred frequently.

At this time it is not known whether the observed variation in crystallization is seasonal or whether large differences can occur in oleoresin obtained from different branches on the same tree. The degree of within-tree stability of resin acid concentration on a seasonal and year-to-year basis in eastern white pine is largely unknown. The measurements of strobic acid concentration and concentrations of the other resin acids that I made were not made at the same time as evaluations of crystallization. Changes in the concentrations of resin acids may be involved in observed differences in oleoresin crystallization at different times.

Weevil larva-induced crystallization. Crystallization induced by crushing insect larva heads into oleoresin is reported to be more rapid than natural crystallization (Yates 1962, Santamour 1965). In this study I found very little difference in crystallization between oleoresin samples treated with crushed weevil larva heads and those allowed to crystallize naturally. Crystallization scores for natural and larva-induced crystallization did not differ by more than 2 points in samples from the same tree. Larva-induced crystallization had higher scores in only 6 samples after 4 hours, 8 samples after 8 and 24 hours, and 12 samples after 3 to 10 days. Correlations between natural crystallization scores and larva-induced crystallization scores in the same trees ranged from a low of .606 at 4 hours to a high of .792 after 3 to 10 days. Most important, introduction of larva heads into oleoresin samples from trees with low concentrations of strobic acid and naturally noncrystallizing oleoresin did not result in crystallization of those samples.

The 10-microliter samples that I used were ideal for testing natural crystallization, but they may have been too small to function properly in larva-induced crystallization tests and that could be one reason why I found little difference between the two methods. Necessary but extensive spreading of the oleoresin droplets on the glass slides when crushing the larvae head can retard crystallization; the sample probably dries before crystallization can occur. Large samples would not dry as quickly.

These results do suggest, however, that the degree of larva-induced crystallization is closely related to natural crystallization. Van Buijtenen and Santamour (1972) induced crystallization in 89 percent of their samples after only 4 hours. Natural crystallization in my study was slower, but it was more rapid than the 4 to 12 days required for stored shoot resins to crystallize reported by Santamour (1965). In the combined sample of 140 trees from both studies, 57 percent had oleoresin that was crystallized at 4 hours, 72 per-

cent at 8 hours, and 87 percent at 24 hours. Only two trees had oleoresin that did not form crystals until 3 days after collection, and crystallization scores for all but a few trees did not change between 3 and 10 days.

Natural crystallization appears to be as useful as larva-induced crystallization for discriminating between trees with crystallizing and noncrystallizing oleoresin. Overall, only 6.8 percent of the oleoresin samples from the trees tested did not crystallize naturally. Van Buijtenen and Santamour (1972) found 9.6 percent noncrystallizers among trees from the same seed sources. Using weevil larva heads to induce crystallization seems to have no special advantage, except shortening analysis time, over natural crystallization for testing oleoresin crystallization properties. Requirements for large oleoresin volumes, ease of contamination of samples with extraneous materials that could inadvertently trigger crystallization, and the precipitate formed in samples with high beta-phellandrene in the oleoresin could be serious disadvantages.

Study II: Crystallization and weevil resistance

Santamour (1965) showed that trees containing oleoresin that would not crystallize in response to contact with crushed heads of weevil larvae appeared to be more resistant to weevil attack, but exceptions did occur. Van Buijtenen and Santamour (1972) also found noncrystallization associated with resistance to weevil attack; but some trees containing noncrystallizing resin were heavily attacked, and some trees containing readily crystallizing resin were attacked unsuccessfully.

Analyses of resin acid composition in 88 eastern white pine revealed only two trees that had no strobic acid (Wilkinson 1979). Both of these trees were heavily weeviled. Now I have found that the oleoresin from both of these trees does not crystallize even after several weeks in storage. I have also found in this study that mean crystallization scores of oleoresin from nonweeviled and heavily weeviled white pine from three plantations, sampled in May and again in June, and observed after 4, 8, and 24 hours and 3 to 10 days, are very similar (Table 4). In many

Table 4.—Mean resin crystallization scores in nonweeviled and heavily weeviled eastern white pine in three plantations in May and in June

Crystallization after:	Weeviling category	Plantation 1			Plantation 2			Plantation 3		
		May	June	May and June	May	June	May and June	May	June	May and June
4 hours	Nonweeviled	0.3	0.8	0.7	1.0	1.0	1.1	0.5	0.8	0.8
	Heavily weeviled	.5	.4	.5	1.2	1.2	1.2	.7	1.0	1.0
8 hours	Nonweeviled	1.1	1.2	1.1	2.0	1.2	1.8	.9	1.2	1.0
	Heavily weeviled	1.1	.7	.9	2.0	1.4	1.7	1.1	1.4	1.4
24 hours	Nonweeviled	1.8	1.6	1.7	2.5	1.7	2.2	1.3	1.6	1.6
	Heavily weeviled	2.0	1.0	1.7	2.6	1.8	2.3	1.6	1.7	1.8
3-10 days	Nonweeviled	2.8	2.6	2.8	3.8	2.7	3.4	2.5	2.4	2.6
	Heavily weeviled	2.9	2.0	2.7	3.6	2.6	3.3	2.9	2.2	2.7

cases mean crystallization scores are higher in nonweeviled trees.

Sign tests for paired comparisons of crystallization scores in nonweeviled and heavily weeviled trees of the same seed sources in each plantation and all three plantations combined were nonsignificant in all cases. Analyses of variance revealed that there were no significant seed source differences in oleoresin crystallization and that seed source pairing was not necessary.

A 2 × 5 table and chi-square test were used to test differences in numbers of nonweeviled and heavily weeviled trees within each crystallization score. There were no significant differences in any of the three plantations, in either May or June, nor at any observation time from 4 hours to 3 to 10 days. Many of the cells contained only a few observations, and the data were combined into two groups. Chi-square tests for independence showed that there were no differences in numbers of trees with crystallizing and noncrystallizing oleoresin between the nonweeviled and heavily weeviled groups (Table 5).

In combined May and June tests more than 50 percent of both nonweeviled and heavily weeviled white pine had oleoresin that crystallized after 4 hours and more than 70 percent of both had oleoresin that crystallized after 8 hours. The number of trees with noncrystallizing oleoresin was much greater in June than in May, and of these trees more than 50 percent were heavily weeviled. At each period except 4 hours in May the heavily weeviled group had more trees with noncrystallizing oleoresin than did the nonweeviled group. Only eight trees had oleoresin that did not crystallize after 3 to 10 days in both May and June. Only two of these trees were nonweeviled; the other six were heavily weeviled. These 8 trees represent 6.8 percent of the total trees sampled, which is very close to the 4.5 percent of 88 trees that had very low concentrations of strobic acid.

This study clearly shows that there is no relationship between crystallization and resistance, but van Buijtenen and Santamour (1972) found that 20 of 209 trees had noncrystallizing oleoresin and that only 3 of these 20 trees had been successfully attacked by the weevil. These differences in results could conceivably be caused by differences in technique: natural versus larva-induced crystallization. However, the differences may be only a consequence of sampling scheme. All 59 nonweeviled trees that I studied had been attacked by the weevil in at least 1 of 3 years, but had survived the attack without leader mortality. In the other years they were free of attack. Most of the trees had, in fact, survived attack in 2 or 3 years. Only 3 of the 17 unsuccessfully attacked trees tested by van Buijtenen and Santamour (1972) were comparable. The other 14 trees had not been attacked at all. Therefore, even in their study, equal numbers of trees that had been successfully attacked and ones that had not been successfully attacked had noncrystallizing resin. Moreover, 11 of their trees that had not been successfully attacked had resin that crystallized.

Eastern white pine trees with oleoresin that does not crystallize are rare. Early selection, before the onset of weevil attack, or selection in lightly weeviled stands and plantations, of

Table 5.—Percentage of nonweeviled and heavily weeviled eastern white pines from which resin crystallized in 4, 8, 24, and 72+ hours

Hours	Date sampled					
	May		June		May and June	
	Nonweeviled	Weeviled	Nonweeviled	Weeviled	Nonweeviled	Weeviled
4	34	44	49	41	58	56
8	69	66	54	49	73	69
24	83	81	64	61	88	85
72+	90	86	81	68	97	90

None of the differences between weeviled and nonweeviled trees are statistically significant.

trees with noncrystallizing oleoresin would produce no more potentially resistant trees than would a completely random selection. Much more important, many potential candidates for resistance breeding programs would not be selected. My studies show that from 48 to 57 white pine from among 59 trees that had resisted weevil attack would not be selected because these trees all had oleoresin that crystallized.

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Abstract

Fertilizers applied in spring can stimulate production of black cherry and red maple seeds in Allegheny hardwood stands. Increased seed production begins in the year after application, but lasts only about 2 years. However, fertilizers do not increase seed production of individual black cherry trees that have a history of poor production, and they do not eliminate seed crop failures, affect seed soundness, or influence the time of seed dispersal.

ADVANCE REGENERATION of black cherry (*Prunus serotina* Ehrh.), red maple (*Acer rubrum* L.), sugar maple (*Acer saccharum* Marsh.), and white ash (*Fraxinus americana* L.) sometimes fails to develop in Allegheny hardwood stands. Failures result in part from the lack of a seed supply adequate to produce the number of advance seedlings needed to establish a new stand.

Good seed years cannot be reliably predicted. Additionally, it is not practical to schedule most regeneration cuttings to follow good seed crops. For these reasons, a way to improve seed production when and where it is needed would be silviculturally desirable.

We examined the influence of fertilizers on seed production in Allegheny hardwood stands as well as on individual black cherry trees that have a history of poor seed production. Time of seed dispersal and seed soundness after fertilization were also determined.

METHODS

In study areas in northwestern Pennsylvania that had been established primarily to determine growth response to fertilization, we also observed the effects of fertilizers on seed crop characteristics in two 60-year-old stands. Although these stands differed in species composition (Table 1), both were representative of Allegheny hardwood stands.

In this experiment, treatment plots of 1.2 acre were established as:

Control—unfertilized

NP—300 lb per acre N from urea and 87 lb per acre P from triple superphosphate

NPK—N and P at above rates plus 83 lb per acre K from potassium chloride

Table 1.—Basal area per acre by species, stand, and treatment, in square feet

Species	Stand 1			Stand 2		
	Control 1	Control 2	NPK	Control	NP	NPK
Black cherry	55	69	49	125	120	104
Red maple	7	10	56	13	5	18
Sugar maple	29	75	14	18	26	5
White ash	22	11	12	3	0	0
Other	8	8	19	26	14	36
Total	121	173	150	185	165	163

In 1972, the fertilizers were uniformly broadcast over the plots in two steps. One-half of the N and all of the P and K were applied at leaf-out time in early May. The balance of the N was applied about July 1. The treatments were repeated in 1973.

In the first stand, we arbitrarily selected the NPK plot to observe the effect of fertilizers on the seed production of black cherry, red maple, sugar maple, and white ash. The estimated production on this plot was compared with the seed production on two control plots. Estimates were made over a 6-year period from 1972 through 1977.

In 1973, we added a second stand. In this stand, we observed the seed crops of black cherry trees from 1973 through 1977. The plots included NP and NPK fertilizer treatments as well as a control.

In both stands, six seed traps were randomly located in each treatment plot. Trap size was 3.0 by 7.3 feet (0.5 milacre). Red maple seeds were trapped from May 15 to July 1, and collected biweekly. Black cherry, sugar maple, and white ash seeds were trapped from August 1 to November 1, and seed collections were made monthly.

Analysis of variance was used to test for significant differences in seed production and seed soundness at the 0.05 level.

In the second experiment, 24 black cherry trees with a history of poor seed production were selected from the superior tree candidates in the black cherry seed orchard program. These trees had an average diameter at breast height (dbh) of 18 inches, an average crown diameter of 25 feet, and ranged in age from 43 to 100 years. The trees were paired to be as alike as possible in age and size, and were located on sites having similar elevation, slope, and aspect—though the physical location varied greatly between the individual members of each pair. In each pair, one tree was fertilized and one was a control.

The fertilizer (NPK) was applied at the same rate with the same carriers as in the first experiment except that all of the N was applied at the same time (mid-May) and only one annual application was made. Application was within a 32-foot diameter plot around each selected tree. Although some roots may have extended beyond this distance, most of the absorbing roots were probably concentrated beneath the crown (Kramer and others 1960, Fayle 1965). For this reason, the treated area was assumed to approximate the feeding zone of the root systems.

The size of flower and seed crops as well as seed soundness were evaluated over a 4-year period (1974-1977). Visual estimates of black cherry flower crops were based on the relative abundance of flowers borne on 20 to 30 twigs long enough to include the current and previous year's growth. These twigs were randomly selected from all sides of the upper one-half of the crown. Seed-crop estimates were based on the total number of fruits on approximately 40 twigs collected at random from all parts of the upper one-half of the crown. Only those trees bearing seed were sampled.

For group comparisons, a t-test was used to test for differences in flower production, seed production, and seed quality, between fertilized and unfertilized trees.

RESULTS

Forest stands

Regardless of treatment, the number of seeds caught in individual seed traps varied considerably. Such variability is common in seed-trapping experiments because seed is not dispersed uniformly over the area and an extremely large number of traps would be required to sample a seed crop adequately. Furthermore, seed production of individual trees is variable. As a result of this variability, extremely large differences between treatments are required to demonstrate statistical significance. Fertilization resulted in such differences for both black cherry and red maple.

Seed production of black cherry and red maple increased after the fertilizer applications of 1972 and 1973. For black cherry, the increased production occurred in the year following the fertilizer application. For red maple, the response was delayed 1 year because of a flower-crop failure. The fertilizer effects lasted about 2 years. In general, the time of the response and the duration of the

Table 2.—Black cherry seed production per acre by stand, treatment, and year, in thousands of seeds

Year	Stand 1			Stand 2		
	Control 1	Control 2	NPK	Control	NP	NPK
1972	41	33	40	[a]	[a]	[a]
1973	222	470	890	108	1,022	1,420
1974	6	3	114	60	552	447
1975	333	317	380	1,749	2,296	2,167
1976	1	0	6	9	116	12
1977	230	173	430	594	674	329

[a] Not trapped.

effect were similar to those reported for beech and sugar maple (Chandler 1938) and for white oak (Detwiler 1943).

Fertilization did not eliminate seed crop failures—no red maple seed was produced in 1973, and no sugar maple or white ash was produced at any time during the study.

Black cherry. Plots fertilized in 1972 and 1973 produced more seed in 1973, 1974, and 1975 than were produced on the unfertilized plots (Table 2). However, increases that resulted from fertilization were statistically significant only for Stand 2 in 1973. Nevertheless, observations made in 1973 and 1974 by climbing trees in both stands confirmed the presence of larger flower and seed crops on fertilized plots than on unfertilized. Based on these observations, and considering the large variations in seed-trap data previously mentioned, we feel that these figures represents meaningful increases.

The soundness of black cherry seed ranged from 84 to 100 percent. Soundness was not affected by fertilization and appeared to vary as much by year as it did by treatment.

Fertilization did not influence the time of dispersal of black cherry seeds. Generally most of the seed crop was dispersed in August.

Red maple. Seed-production data for red maple were collected only in Stand 1. It is apparent from Table 3 that the NPK treatment did not prevent a seed crop failure in 1973. Red maple flowered in that year but failed to produce any seed. This seed-crop failure was probably caused by temperatures below freezing in late April and early May, suggesting that fertilization does not improve the frost hardiness of the flowers.

Table 3.—Red maple seed production per acre in Stand 1 by treatment and year, in thousands of seeds

Year	Treatment		
	Control 1	Control 2	NPK
1972	413	[a]	646
1973	0	0	0
1974	138	91	762
1975	83	38	621
1976	0	6	0
1977	193	4	172

[a] Not trapped.

Seed-crop failures have not been eliminated, but crops increased in some years. In 1972, before red maple seed crops were affected by fertilization, there was no significant difference in seed production between fertilized and unfertilized plots ($P<0.05$). Because seed crops failed on all plots in 1973, it was not until 1974 that fertilizer effects on seed production were first observed. In that year and in 1975, seed production was 6 to 10 times greater on the fertilized plot than on the controls. These differences were statistically significant at the 0.05 level in 1974 and the 0.10 level in 1975. By 1977, the fertilizer effects had worn off. Seed production on the fertilized plot had dwindled to about 25 percent of that achieved in 1974 and 1975 and was about equal to the production on the unfertilized controls.

Seed production of a stand is strongly influenced by the basal area per acre of the seeding species. The fertilized plot had more basal area in red maple than the control plot

and might, therefore, be expected to have higher red maple seed production even without fertilization. Although this might be true for the stand as a whole, the limited data from the seed traps do not show this—seed crops in 1972 and 1977, unaffected by fertilization, were not significantly different at the 0.05 level. Thus, the increases shown in the seed-trap data appear to be real effects of treatment, and not due to the greater basal area.

The soundness of red maple seed ranged from 76 to 86 percent. Soundness was not affected by fertilization and it varied as much or more by year as it did by treatment.

The time of seed dispersal was not influenced by fertilization. Red maple seed crops were dispersed in late May and early June.

Individual trees

In the second experiment, fertilizing individual black cherry trees that had a history of poor seed production did not improve the size of flower or seed crops.

The average number of flower racemes per twig (Table 4) did not differ significantly at the 0.05 level by treatment in any year of the study.

Only one of the sample trees produced seeds in 1974. This tree, fertilized in 1973, averaged 5.2 racemes per twig and 4.2 fruits per raceme. In 1975, seed production was slightly better. Seven of the 24 sample trees bore some seed—3 fertilized and 4 unfertilized trees. There was an average of 2.1 racemes per twig regardless of treatment and the average number of fruits per raceme was about the same—3.0 fruits when fertilized, 3.1 when not. All seeds collected were sound.

Table 4.—Average number of flower racemes per twig by year and by treatment, in second experiment

Year	Treatment	
	Fertilized trees	Unfertilized trees
1974	0.20	0.15
1976	0.66	0.94
1977	1.01	0.61

DISCUSSION

Fertilization can increase seed production of black cherry and red maple in forest stands. Often the differences in seed production between fertilized and unfertilized stands were not significant, however, the differences in numbers of seeds produced can be important for regenerating a new stand. These differences are especially important for red maple whose seed does not remain viable in the forest floor for more than 1 year (Bjorkbom 1979, Marquis 1975) and for all species when poor seed crops might be expected.

The influence that fertilization might have on regeneration can be estimated from data from an earlier study of red maple seed and seedling production (Bjorkbom 1979). In that study, the average ratio of seeds to seedlings was estimated at about 6 to 1. Based on this, the estimates of seedlings produced from the red maple seed crops of 1974 and 1975 would be:

	Number of seedlings expected per acre	
Seed year	*Fertilized stands*	*Unfertilized stands*
1974	127,000	19,100
1975	103,500	10,100

These data indicate that a fertilized stand may produce up to 10 times as many red maple seedlings as would be produced in an unfertilized stand. This may mean the difference between adequate and inadequate regeneration.

Black cherry seeds differ from red maple seeds in their ability to remain viable in the humus for a period of years (Wendel 1977, Marquis 1975). Nevertheless, stimulating black cherry seed production in a poor seed year may be important in building up and maintaining advance regeneration. In a poor seed year, a fertilized stand can yield seven or more times as much black cherry seed as an unfertilized stand. This additional seed plus the seed stored in the humus ensures a relatively stable annual supply.

In fertilized forest stands, seed production was improved but this result was not achieved

by fertilizing individual black cherry trees that were inherently poor seed producers. These trees failed to show any increase in flower or seed crops.

Failure to produce seed is not uncommon in black cherry. Grisez (1975) reported that in a forest stand, 8 percent of the dominant and codominant cherry trees 10 inches in dbh and larger failed to produce more than a few seeds. However, when trees were selected for rapid growth, excellent tree form, and high veneer quality as the trees in the black cherry seed orchard program were, one-third of these trees produced only negligible amounts of seed. Whether or not all trees chosen for these qualities are characteristically poor seed producers is not known. But unfruitful trees do exist, and they must be taken into consideration in evaluating the regeneration potential of a stand.

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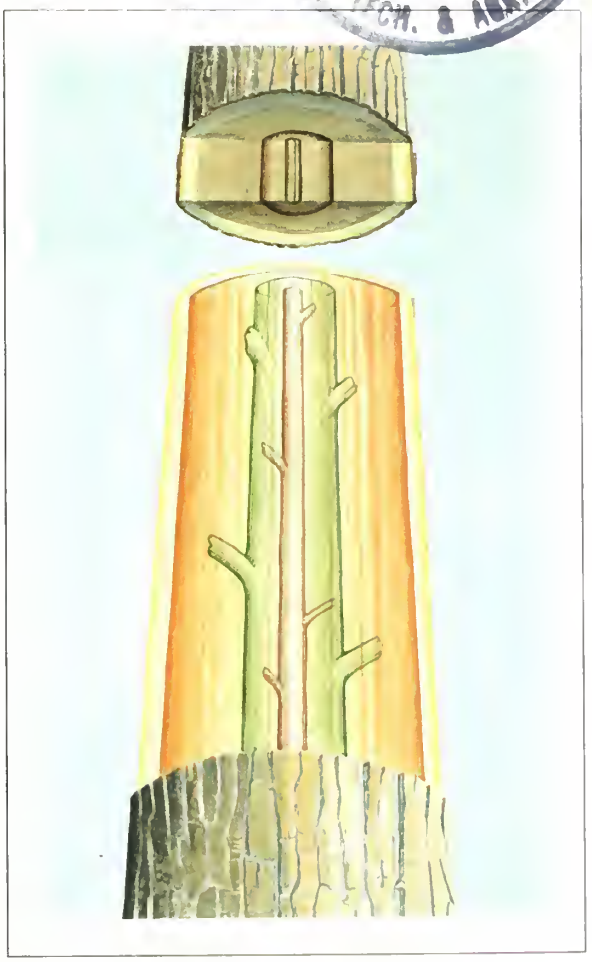
by Alex L. Shigo, E. Allen McGinnes, Jr.,
David T. Funk, and Nelson Rogers

Internal Defects Associated with Pruned and Nonpruned Branch Stubs in Black Walnut



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ABSTRACT

Dissections of 50 branch stubs from seven black walnut trees revealed that some discolored wood was associated with all stubs, and that ring shakes and dark bands of discolored wood were associated with 14 of 17 stubs that were "flush cut" (branch collar removed) 13 years earlier while they were living or dead. Ring shakes formed along the barrier zone tissues that separate the wood formed before wounding from wood that formed subsequently. Pruning done early in the life of the tree eliminates these problems. When pruning is done late in the life of a tree, care must be taken not to remove the branch collars that form around the bases of dying and dead branches. A pictorial description of the internal defects associated with the pruned and nonpruned stubs is presented.

BRANCH PRUNING is not a "cure all" for defects in black walnut (*Juglans nigra* L.). Proper pruning that is begun early in the life of a tree and continued as needed can be beneficial most of the time. Improper pruning at any time will cause problems. But what is proper pruning?

The high value of black walnut as timber necessitates a reevaluation of our pruning techniques. Of particular concern is the recommendation that *all* branches be *flush cut* (implies removal of branch collar). How this is interpreted and performed could make the difference between growing trees with little defect or with a great amount of defect.

With photographs of actual dissected stubs, and with diagrammatic paintings, this paper will show the defects associated with pruned and nonpruned branch stubs. This extends the information published on pruning black walnut on strip mine spoils. Because most of the introductory material and the literature cited are similar for both studies, they will not be repeated here. For these details, see Shigo et al. (1978).

BLACK WALNUT

The value of black walnut depends on many factors, but one of the most important is the amount of defect-free wood in the stem. The major defects are knots, discolored and decayed wood, and ring shakes.

Discolored and decayed wood and ring shakes can be associated with many types of wounds, including those that result from dead, broken, and pruned branches.

Black walnut, like other trees, is a highly compartmented plant that compartmentalizes injured and infected wood associated with wounds. This process confines defects within the diameter of the tree at the time of wounding. This is of benefit to tree managers and buyers because a defect is not so important if it is restricted to a small volume in the center of the tree. For example, if a tree is wounded severely when it is 3 inches in diameter, the worst that can happen is that a 3-inch core of defect will develop. The decay caused by fungi will not spread to the growth rings that form after wounding even in heartwood—because,

After wounding, the cambium forms a distinctly different tissue called the barrier zone. Decay usually starts in the discolored sapwood and not in the exposed heartwood; and it does not spread progressively to the center of the tree as is implied in the classic heartrot concept. Details on compartmentalization of decay and the formation of barrier zones are published (Shigo and Marx 1977).

The barrier zone is a very strong protection against further infection, but it is also a plane of structural weakness because it has a different anatomical and chemical makeup from normal wood. When internal stresses caused by rapid temperature changes or wind occur near the barrier zone, the wood may separate tangentially and longitudinally along the barrier zone which results in a ring shake. The ring shake could trigger separations along other planes of weakness and radial separations may develop from the inside of the stem outward to the bark resulting in a radial seam or "frost crack."

THE ORIGINAL STUDY—1965

In February 1965, 77 planted black walnut trees were selected for study at the Crab Orchard National Wildlife Refuge near Carbondale, Illinois. The objective of the study was to improve the growth of pole-size trees by overstory release, understory release, and fertilization. Although pruning was not a part of the study, the sample trees were pruned to 25 feet with a pole saw when thought necessary. The trees were 25 years old. This is considerably older than the recommended age for pruning plantation-grown walnut trees. The site index has been calculated as 75 for age 50.

DISSECTION OF TREES—1977

In November 1977, six trees considered to be representative of moderate-growing specimens, and one slow-growing specimen were cut. Nonpruned stubs varied in age. Care was taken to dissect the branch stubs longitudinally through the pith. After they were cut into 2-inch-thick boards, all cut surfaces of the samples were planed. The boards were sent to the Forestry Sciences Laboratory in Durham, New Hampshire, for further study after sanding and drying. In this paper, "stub" is used to define the remaining basal portion of a cut or fallen branch, whether the portion is embeded entirely in the trunk or slightly protruding.

On six of the trees, all 13-year-old pruned stubs were closed. These 38-year-old trees were growing at a moderate rate, and the diameters at breast height (dbh) ranged from 9 to 13 inches. One tree was growing very slowly and had a dbh of 5.9 inches. Four of the five pruned wounds on this tree were still open.

OBSERVATIONS

Discolored wood was associated with all pruned and nonpruned stubs, but very little was associated with the small nonpruned stubs. Ring shakes were associated with 14 of the 17 stubs that were flush cut. Four stubs did not have their branch collars removed when pruned, and no ring shakes were associated with them. Most of the stubs without branch collars were dead at the time of pruning. In these cases, the ring shakes formed between the growth ring present at the time of pruning and the growth ring that formed the year after. The ring shake separation was along the barrier zone formed by the cambium after wounding. In some stubs, ring shakes also formed at the barrier zone formed when the branches died.

Many of the stubs had long flush pruning cuts (elliptical; long axis vertical). Some were over 8 inches long for branches recorded as 2.5 inches in diameter in 1965. The long cuts often resulted in multiple ring shakes. It was obvious that the protruding branch collars or bumps were cut along with the dying or dead branch, which resulted in large wounds. The sprouts that formed around some of these pruned branches were cut 1 year later, and some ring shakes formed along the barrier zone that formed that year.

Decayed wood was associated with the large open branch wounds on the slow-growing tree, but even then the decayed wood compart-

mentalized within the tissues present at the time of branch death. Small compartmentalized pockets of decayed wood were associated with many branch stubs, especially the nonpruned stubs.

Radial seams were associated with two flush-cut branch stubs. The radial seam formed deep in the tree along the pith and developed outward toward the bark.

Insect galleries made by ants were obvious in many stubs.

SUMMARY & RECOMMENDATION

Branch collars, which form rapidly as branches die, appear to be a characteristic of black walnut. Pruning cuts that remove the branch collar can cause serious internal defects in black walnut. When pruning is to be done, it should be started early in the life of the tree and continued as needed. If small branches are pruned on young trees, pruning cuts flush with the bole can be made and very little to no injury will result because the branch collars will be very small. On older trees, great care must be taken not to prune the branch collars flush with the stem because the dying and dead branches are already compartmentalized.

When a branch collar is removed, a second, more severe wound is created. Such a cut removes the protective chemical zone that formed in the branch stub as the boundary between the decay spreading inward from the dead branch and the healthy wood of the stub. When this zone is removed, the stub is vulnerable to infection. Although flush cuts may result in straight boles, a great amount of defect may result from ring shakes and bands of discolored wood. Also, the ring shakes can act as planes of weakness for radial separations. When radial separations break out to the cambium, a seam usually called a "frost crack" forms.

The patterns of dark-colored bands often seen in the heartwood of black walnut are also associated with branch stubs, and the large flush cuts initiated the longest columns of discolored wood in the samples investigated.

Great care must be taken not to interpret flush cut as the removal of the branch collars —this is especially important in chain-saw pruning and high pruning with pole saws. It is better to have shorter lengths of high quality, defect-free wood than to have long lengths of defective wood.

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The watercolor illustrations are by David M. Carroll, Warner, New Hampshire.

Figure 1.—The study at Crab Orchard, near Carbondale, Illinois. The arrow shows the position of two pruned stubs. All pruning wounds (arrow) were closed on the six fast-growing trees dissected.

Figure 2.—The pruning wounds on one slow-growing tree were still open after 13 years. Wound closure is directly related to the increment of growth after wounding. Wounds on fast-growing trees close more quickly than those on slow-growing trees.

Figure 3.—A decayed branch stub on a black walnut tree. As the stem tissues grow around the stub, a bump or bulge forms as a collar. The large arrow shows the position of the barrier zone, which is the tissue formed by the tree after the branch died. Any discolored or decayed wood associated with the stub will be confined to the inner side of the barrier zone. The small arrows indicate bud traces.

Figure 4.—A pinched-off decayed branch. The microorganisms that cause decay are beneficial because they aid in the breakdown of dead organic matter that is essential for new life. As the decay process develops, the tree begins to form a chemical protection zone within the stub, as shown here by the arrows. Normally, the branch will be decayed back to this zone. Here, a plane of great strength and a plane of great weakness meet, and stress from wind, ice, snow, etc. can cause the branch to break at this point. The tissues around the stub then close the wound.

Figure 5.—A well-closed branch stub. When all systems function properly, the branch is enclosed in the stem. Even if some decayed wood develops, it will be confined by the branch stub chemical zone (large arrows). A slight bump may form as the stub wound is closed. The barrier zone, which formed after the branch died (small arrows), usually—but not always—results in a darker growth ring. Should microorganisms invade the tree through the stub, they would be confined to the inner side of the barrier zone.

Figure 6.—A long stub associated with a large bump. The dead branch remained on the tree for a long period, and decayed to the boundary of the chemical zone (large arrows). Note the almost horizontal angle of the stub. This may have prevented early abscission. The small arrows show the position of the barrier zone that formed after the branch died. Note the dark band of wood on the inside of this zone.

Figure 7.—An enclosed small stub. This stub broke before it fell from the tree, and the arrow shows the extent of the decayed wood and the cracked base of an old branch. The broken stub, even on this very small branch, greatly increased the time required for closure.

Figure 8.—Compartmentalization of decayed wood associated with a large branch stub (large arrows). The branch broke and aparently stayed attached for a long time (open arrow), preventing rapid closure. But, even though decayed wood developed, it was compartmentalized within the tissues present at the time of branch death. Note also that the decayed wood is surrounded by nondecayed heartwood. A dark band separates the compartmentalized decayed wood from the sound heartwood. Multiple ring shakes were associated with the stub (small arrows).

Figure 9.—Proper pruning cut of a large dead branch. When pruning is done late in the life of a tree, great care must be taken not to remove the branch collar or bump that developed around the branch.

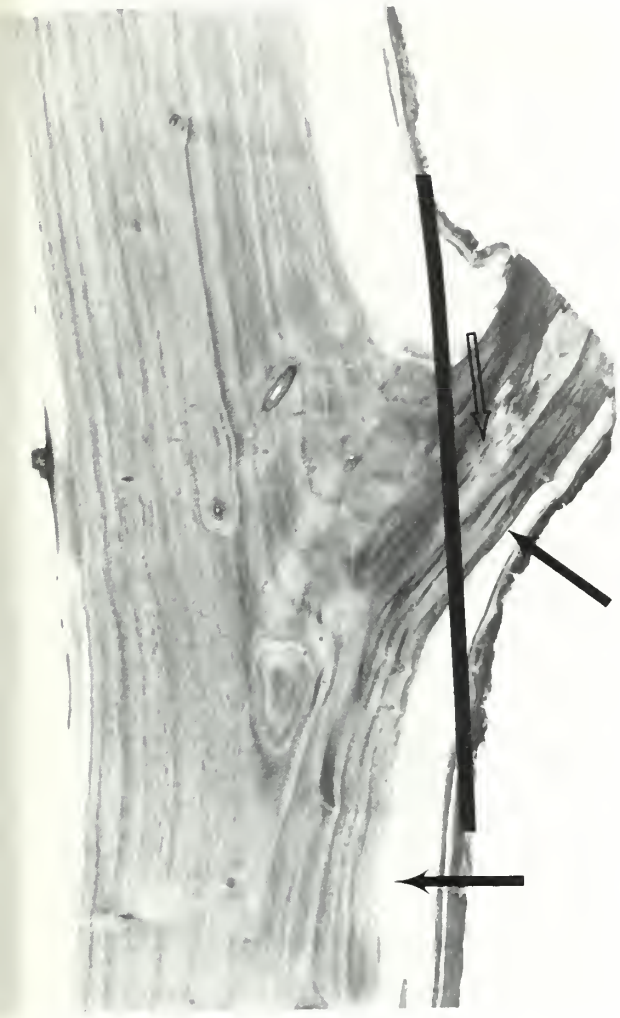


Figure 10.—Large bump associated with an old dead branch. A proper pruning cut was made. A flush cut would follow the dark solid line. This would create a new, more serious wound. The barrier zone associated with the branch has been formed (large arrows). Any further development of discolored or decayed wood would stay on the inner side of this zone. If the flush cut were made, the decayed wood (open arrow) would spread rapidly beyond the old barrier zone.

Figure 11.—A flush cut of a dead branch. Improper pruning removes the large bump or branch collar. The barrier zone associated with the dead branch is shown by the open arrow. A new barrier zone would develop at the position shown here by the large arrows. The small arrows show the boundary of the heartwood. A large flush cut of this type would give the tree a straighter form at the expense of potential ring shakes and dark bands of discolored wood.

Figure 12.—A large flush cut similar to that shown in Figure 11, but 13 years later. The distance between the open arrows is 7 inches. The branch at the time of the cut was less than 2 inches in diameter. The large arrows show the large ring shakes that developed between the growth ring present at the time of wounding and the one that formed subsequently. Also, the heartwood on the inner side of the ring shake was discolored. The small arrows point out a dark band associated with an older dead stub.

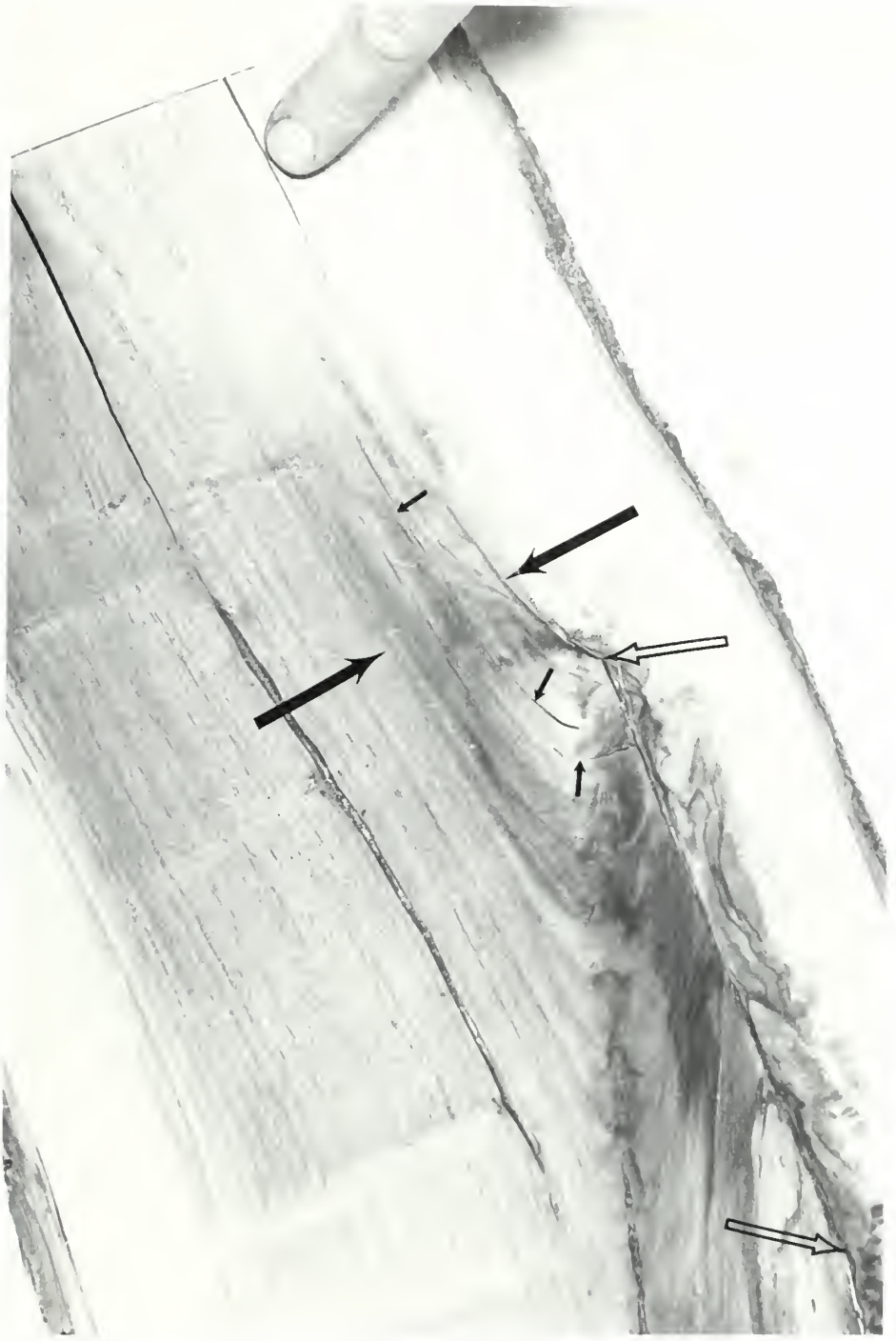


Figure 13.—A 7-inch, 13-year-old flush cut (open arrows). Note decayed wood beginning to form at the upper and lower limits. The large arrows show the dark band of discolored heartwood associated with the flush pruning wounds. The finger points to a large ring shake associated with the wound. The shakes usually opened more at the ends of the sample boards. The large open shake was between the growth ring that was present at the time of the wound and the ring that formed the following year. The small arrows show smaller ring shakes within the band of discolored heartwood. Bacteria, nondecay fungi, and decay fungi are commonly associated with the discolored and decayed bands of defective heartwood.

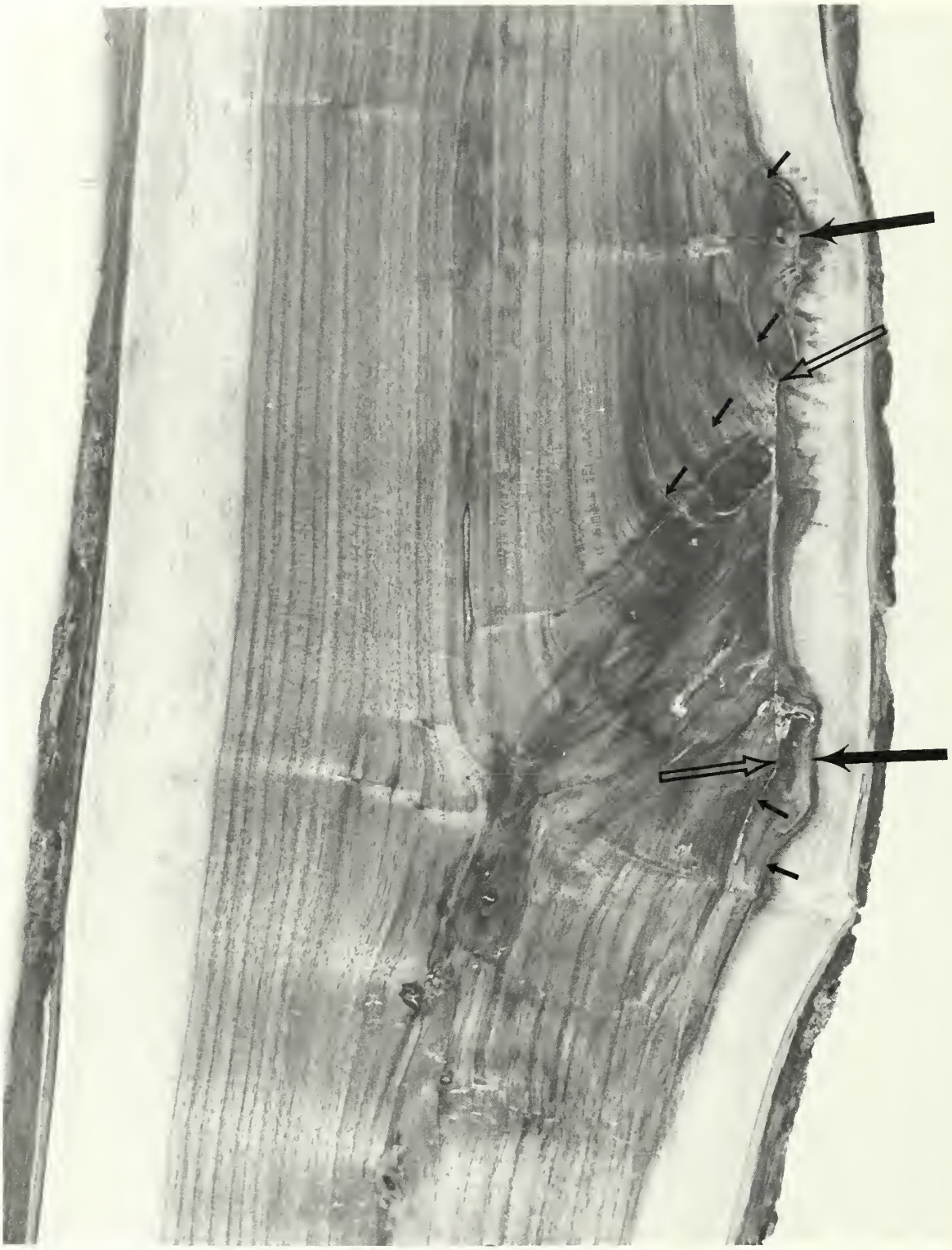


Figure 14.—Multiple ring shakes (small arrows) associated with a large flush cut and the subsequent removal of sprouts (large arrows). A thick band of discolored heartwood was also associated with the wounds. The original flush cut was 5 inches long (open arrows).

Figure 15.—A 2½-inch flush cut (open arrows) that did not remove the V-shaped chemical protection zone in the stub (small arrows). A dark streak developed (large arrows), but no ring shakes.

Figure 16.—Pockets of decay starting in discolored sapwood in a dead stub (large arrows). When decay develops in a stub it usually starts in the discolored sapwood and not the exposed heartwood, as is stated in the heartrot concept. Note that the heartwood in the stub is sound (open arrows). The small arrows show the barrier zone associated with the stub. The decay would be confined to the inner side of this zone. The discolored zone is longest along the heartwood-sapwood boundary in the stub.

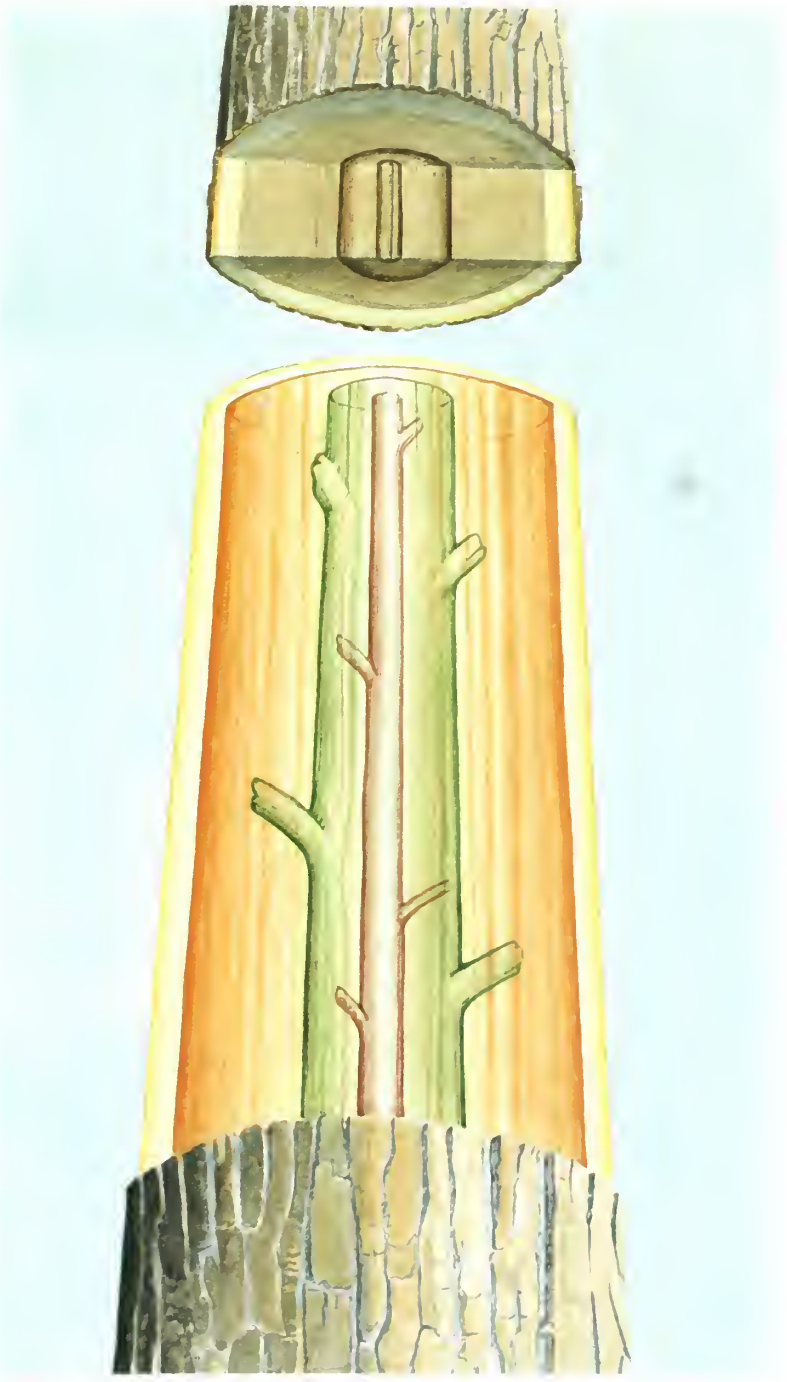
Figure 17.—Most of the time the tree's defense systems function properly, and even when decay develops in the discolored sapwood of the branch, it does not continue to spread into the tree after the branch falls. The large arrows show the old decay pockets that were in the dead branch before it fell. The open arrow shows the position of the barrier zone. The flat, straight closure of the stub wound suggests that the old decaying stub was forced off by the pruning saw blade.

Figure 18.—Advanced decay (large arrows) associated with a flush cut dead branch on a very slow-growing tree. Note the position of the decay—it did not spread to the center of the tree as implied by the heartrot concept. The decay is advancing through discolored wood and is not spreading inward through nonaltered or nondiscolored heartwood. The open arrows show the advanced discolored wood that would later become decayed. The indentations shown by the small arrows indicate that decay was well established in the sapwood before the branch was cut. Insect galleries are obvious in the decayed wood above the stub.

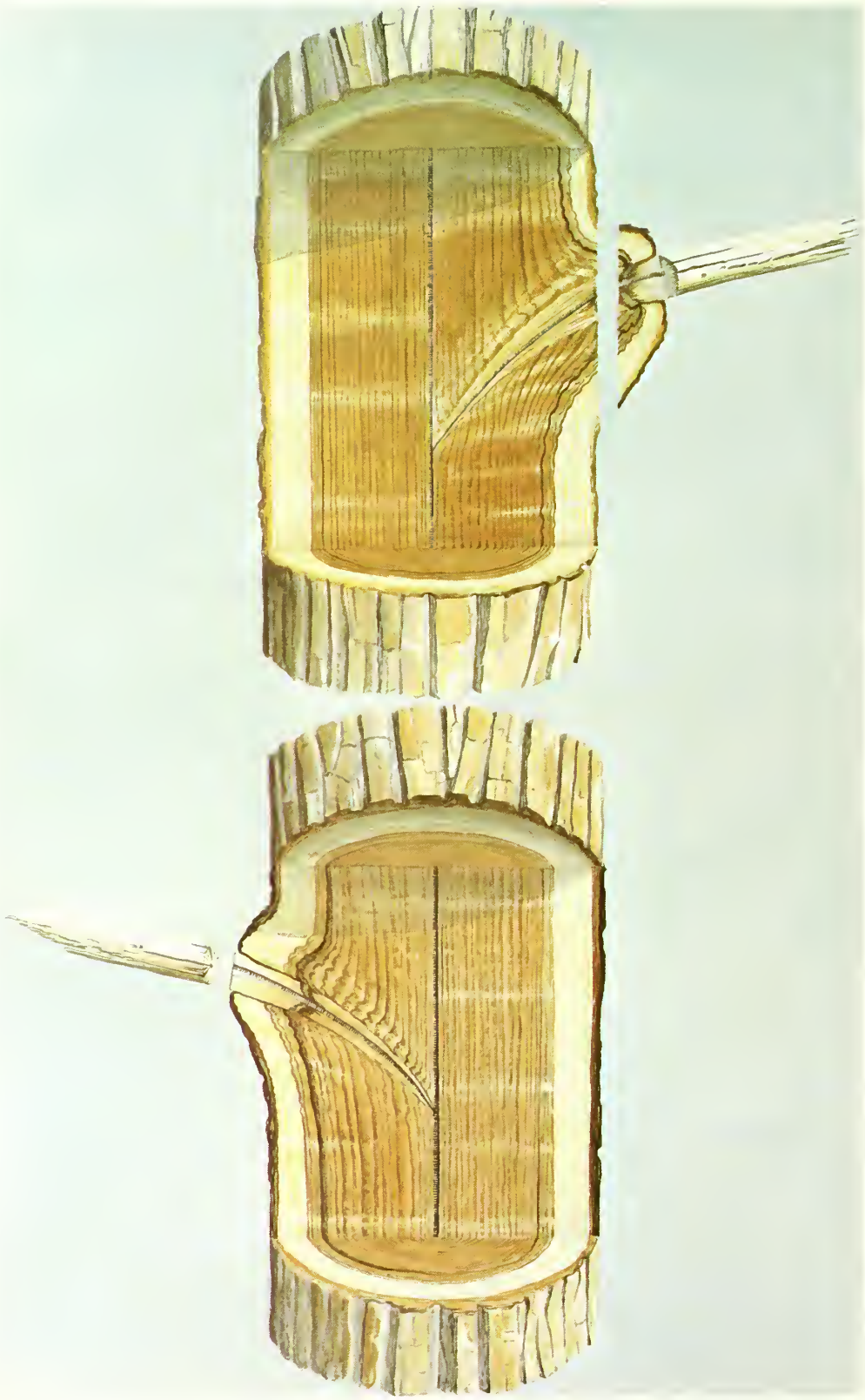
Figure 19.—Advanced decay associated with a large open 13-year-old pruning wound on a very slow-growing tree. Note that the outer portion of the stub is decayed, but the inner core of the stub and the tree are still sound. The large arrows show the inner compartment of sound wood. Yet, the heartrot concept would lead you to believe that the center of the tree would be decayed before the outer core. The decay did not penetrate this inner core of heartwood because it was already walled off by a barrier zone from some previous injury or loss of a branch. Decay-causing fungi *do not* grow indiscriminately through heartwood or sapwood in a living tree. The large open arrows show large ring shakes in the discolored heartwood.

Figure 20.—Large pockets of advanced decay associated with an open nonpruned stub in a very slow-growing tree. The arrow indicates the diameter of the tree when the branch died. Heartwood formation was stalled because at this point there are over 25 rings of sapwood. The decay did not spread outward into the tissues that formed after the death of the branch. Many factors contributed to this advanced column of defect, but the two major ones were the slow growth of the tree and the insect infestation deep into the stub beyond the chemical protection zone. Stubs should be pruned before insects infest beyond this zone.

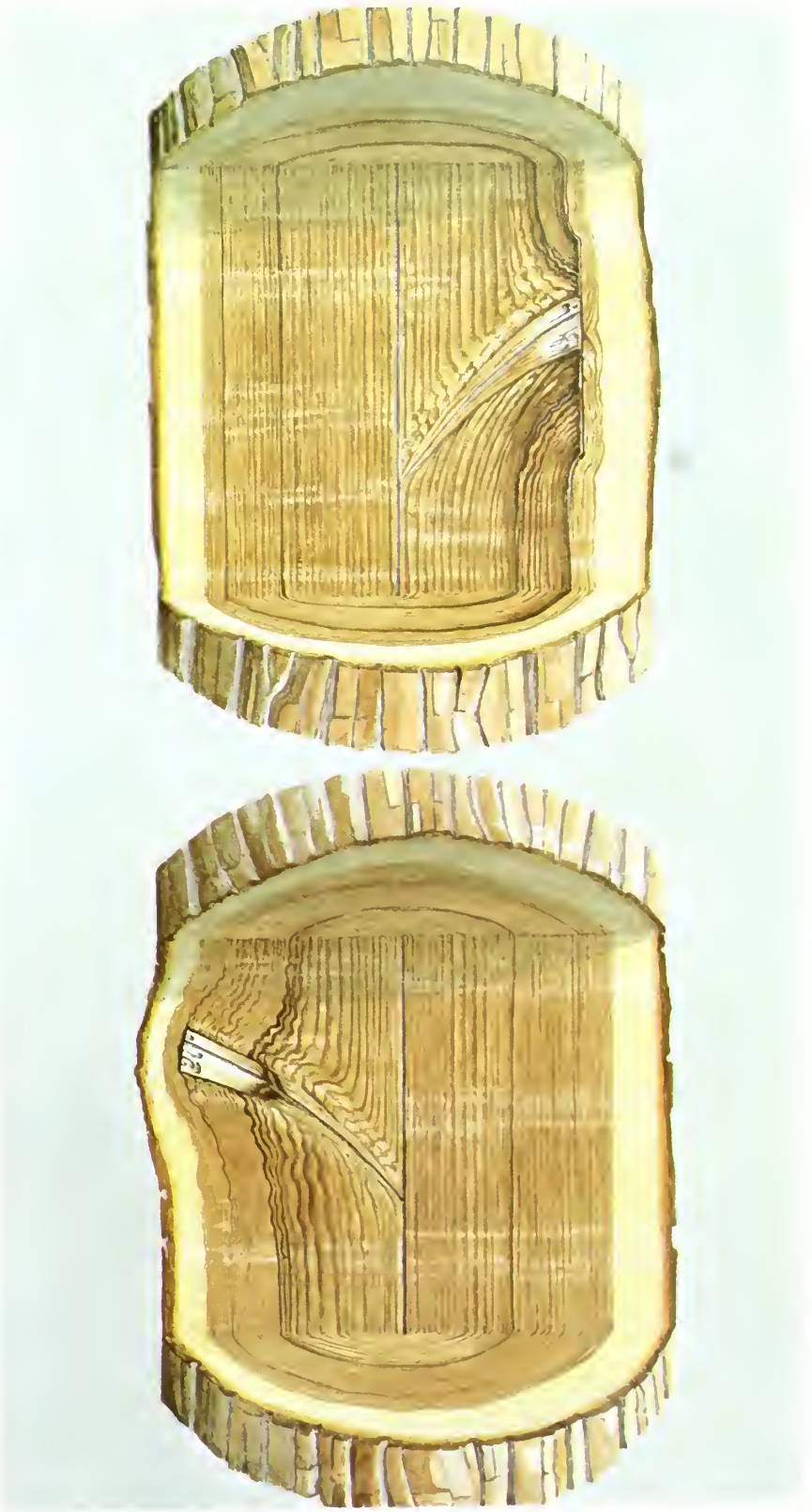
Figure 21.—A large radial seam was associated with this pruned stub (large arrow). Insects had infested deep into the stub (open arrow). Ring shakes were also present (small arrows). As wind or temperature extremes stress the tree, the radial seam may split from the inside outward. A typical "frost crack" would then form. Such cracks are usually to the sides of branch stubs.



Different types and conditions of wood in black walnut: sapwood (yellow), heartwood (orange), discolored heartwood (green), and decayed wood (brown). When several wounds are inflicted at about the same time or when several branches die at about the same time, the associated altered wood will be compartmentalized within the cylinder of wood present at the time of wounding or branch death. Decayed wood is usually obvious after a tree is cut, but identifying discolored heartwood could be a problem. It may go unnoticed until veneer is made or until the wood is made into a product.

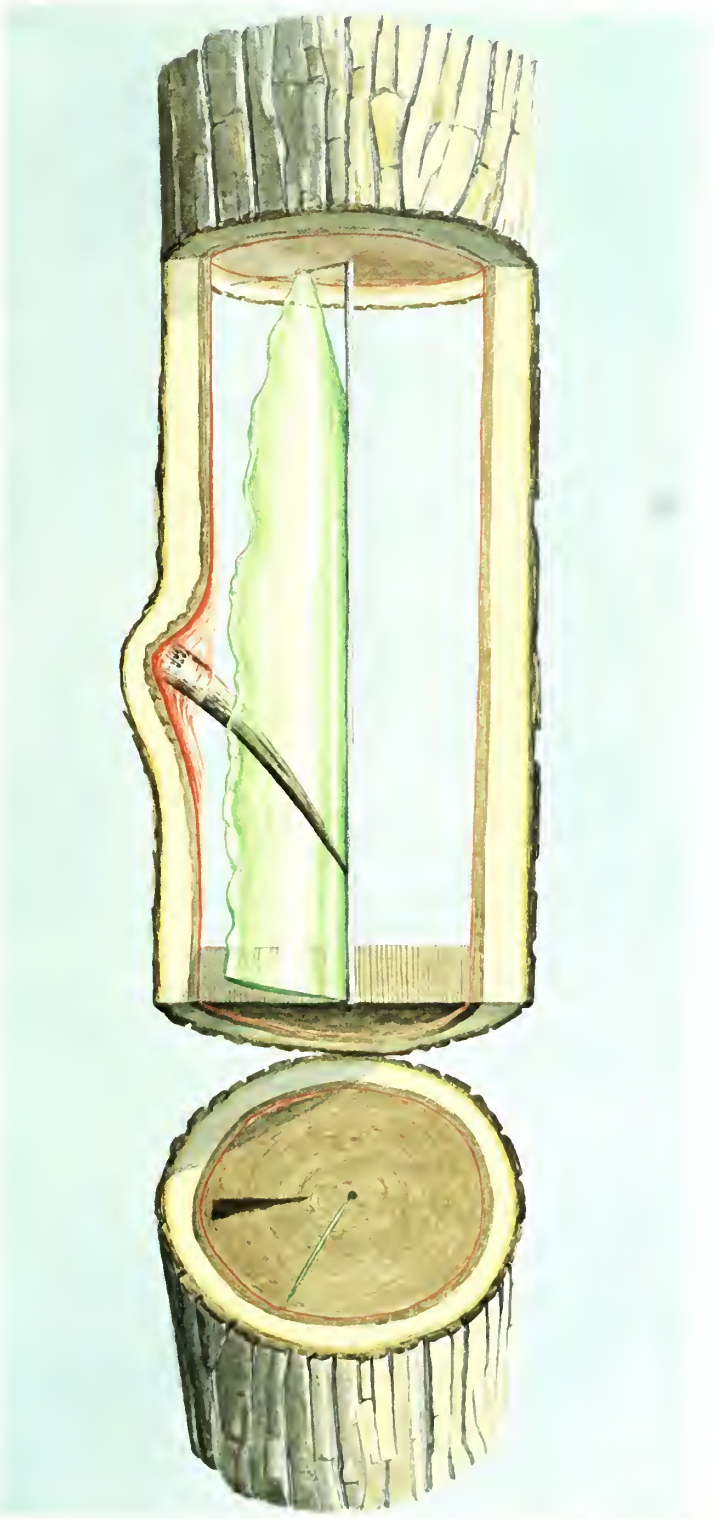


Improper (above) and proper (below) pruning cuts for dead branches that have large collars.



Internal condition of wood associated with closed wounds after improper (above) and proper (below) pruning of dead branches.

The growth ring that forms after a branch dies (pink) will often have an area that is slightly darker above and below the stub (blue). These bands of darker wood are seen commonly in black walnut.



Radial separations sometime develop off to the side of a stub (green). They may break out to the bark and become visible radial seams. After a branch is pruned, a barrier zone forms (red). It may cover a small area around the stub or it may go entirely around the trunk. The barrier zone is both a chemical and an anatomical zone. It is not always visible.

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